Transport Canada
Development

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TP 8407E

Proceedings

of the
Precise Navigation Workshop
November 13, 1986

Canada

TRANSPORT CANADA TRANSPORTS CANADA

TP8407E

PROCEEDINGS

OF THE

PRECISE NAVIGATION WORKSHOP

NOVEMBER 13, 1986

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Transport Canada / Transports Canada
Development / Développement

89-06082/

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP8407E	N/A	

4. Title and Subtitle	5. Report Date
PROCEEDINGS OF THE PRECISE NAVIGATION WORKSHOP	NOVEMBER 13, 1986
	6. Performing Organization Report No.

7. Author(s)	8. Transport Canada File No.
M. Walker, P. Eng. (Editor)	D1460-233

9. Performing Organization Name and Address	10. DSS File No.
Transportation Development Centre (TDC) Guy-Favreau Complex 200 Dorchester Blvd. West, Suite 601, West Tower Montreal, Quebec H2Z 1X4	N/A
	11. DSS or Transport Canada Contract No.
	N/A

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Transportation Development Centre (TDC) Guy-Favreau Complex 200 Dorchester Blvd. West, Suite 601, West Tower Montreal, Quebec H2Z 1X4	Proceedings
	14. Sponsoring Agency Code
	N/A

15. Supplementary Notes	16. TDC Project Officer
Co-sponsored by the Dominion Marine Association	N/A

17. Abstract

Proceedings of a one-day workshop attended by representatives of industry, government and academia from Canada and the U.S. to present and examine the research and development activities relating to precise navigation sponsored by the Transportation Development Centre. The results of these R&D activities, including a comparative analysis of technologies, are presented by the respective researchers. The workshop included a discussion period and concluded with recommendations from the participants on future R&D requirements and priorities.

18. Key Words	19. Distribution Statement
Precise marine, ship navigation, seaway, arctic, harbours, microwave, global positioning, integrated, PRANS	Limited number of copies available from the Transportation Development Centre

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Nil	Nil	155	Nil

TDC CDT 79-005
Rev 86

Canada

Transports Canada / Transport Canada

Développement / Development

FORMULE DOCUMENTAIRE DU RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP8407E	N/A	

4. Titre et sous-titre	5. Date du rapport
PROCEEDINGS OF THE PRECISE NAVIGATION WORKSHOP	13 novembre, 1986
	6. N° du rapport de l'organisme exécutant

7. Auteur(s)	8. N° de dossier Transports Canada
M. Walker, P.Eng. (Editeur)	D1460-233

9. Nom et adresse de l'organisme exécutant	10. N° de dossier — ASC
Centre de développement des transports (CDT) Complexe Guy-Favreau 200 ouest, boul. Dorchester, suite 601, tour ouest Montréal (Québec) H2Z 1X4	N/A
	11. N° de contrat — ASC ou Transports Canada N/A

12. Nom et adresse de l'organisme parrain	13. Genre de rapport et période visée
Centre de développement des transports (CDT) Complexe Guy-Favreau 200 ouest, boul. Dorchester, suite 601, tour ouest Montréal (Québec) H2Z 1X4	Actes de l'atelier
	14. Code de l'organisme parrain N/A

15. Remarques additionnelles	16. Agent de projet — CDT
Co-parrainé par Dominion Marine Association	N/A

17. Résumé

Actes de l'atelier d'une journée auquel ont participé les délégués des secteurs public et privé ainsi que des universités du Canada et des États-Unis en vue de présenter et d'examiner les actions de recherche et de développement lancées par le Centre de développement des transports dans le domaine de la navigation de précision. Les comptes rendus des travaux et l'analyse comparative des technologies en présence ont été présentés par les chercheurs respectifs. À la fin de la période de débat prévue, des recommandations ont été formulées par les participants en ce qui concerne les nouvelles recherches à lancer et l'ordre de priorité à respecter.

18. Mots-clés	19. Diffusion
Navigation maritime de précision, navigation maritime, voie maritime, arctique, ports, hyperfréquences, positionnement global, intégré, système PRANS	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
non classifié	non classifiée	155	Nil

CDT/TDC 79-005 Rev 86

Canada

PRECISE NAVIGATION WORKSHOP

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PROCEEDINGS OF THE WORKSHOP ON PRECISE NAVIGATION

Opening Remarks

Mr. N.E.(Ted) Rudback Executive Director of the Transportation Development Centre (TDC) Montreal welcomed the delegates on behalf of the TDC and Transport Canada.He noted that the workshop was sponsored jointly by Transport Canada(TC) and the Dominion Marine Association(DMA).TDC originally became involved in precise navigation at the specific request of the Dominion Marine Association and the Canadian Coast Guard(CCG).TDC have worked in close collaboration with the DMA over the last several years on the problem of precise navigation.The subject is of broad interest to the entire marine community as indicated by the attendance of so many specialists intrested in this technology from all across Canada and from the US Coast Guard.This session should produce a good assessment of the technical accomplishments to date.

This workshop represents a milestone in TDC's efforts in precise navigation.It is now time to examine the work that has been carried out and reflect on where we wish to go in the future.We will have technical presentations on:system accuracy requirements and operational requirements,technical studies into the various ways these requirements could be met and some appreciation of the costs and potential benefits of the proposed solutions.Precise navigation systems are already being deployed into ports and harbors around the world to permit entry under all weather conditions.The specific applications TDC were investigating with the DMA related to confined waterways and channels.However,we are finding that the generic technologies have applications to ports and to areas of particular interest to Canada most notably in the Arctic where navigation aids do not presently exist.

Technology has evolved to the point where we can now seriously contemplate blind navigation in confined waterways.However,precise navigation systems must not only be technically feasible but economically feasible as well.

Today we would like to outline the technical results and open them to examination by experts in the field.We must determine,in a technical sense,some of the promising avenues for research and development and examine some of the potential applications for precise navigation technology.We must bear in mind that we operate in an era of intense restraint.Budgets in Transport Canada are very restricted, and the private sector is feeling the results of deregulation and intense competition.Investment will be restricted to those areas where it can be shown to provide a positive return on investment either to the private sector or to the government.We can almost certainly expect that if Transport Canada invests in any public infrastructure, some form of cost recovery will be needed.

In closing Mr. Rudback introduced Mr.Leslie MacArthur,manager of marine operations and regulation for the DMA.

Mr.MacArthur noted how pleased he was to see how many people were showing an interest in precise navigation technology and although DMA were not at the present time able to continue supporting it financially they are interested in the results and would hope to see future implementations on their ships.

Mr.Rudback introduced the moderator for the morning session Mr.Richard Bertrand Chief,Transportation Systems Technology with TDC.

Morning Session:Operational Requirements

Mr Bertrand welcomed the delegates and provided a brief introduction to the theme of the morning session "Operational Requirements".

As a background Mr. Bertrand gave a short history of TDC's involvement in precise navigation systems technology which goes back to the early 1970's when TDC, DMA and the Canadian Coast Guard began testing a system called PRANS,or Precise Radar Navigation System.This system originated in the United States in a company called Associate Communications and Controls Inc.(ACCI).Testing the technology and reviewing the findings by a steering committee composed of representatives from: DMA,CCG,Department of Communications(DOC),the Saint Lawrence Seaway Authority(SLSA) and the National Research Council(NRC) found that,although there were shortcomings in the technology as tested, the basic idea was deemed to be worthy of further development.This development was necessary before hard investment could be made in any given system.The development has involved many people and agencies,whether owners and operators or engineers and researchers and all have come to realize that precise navigation was many things to many people.

Introductory Remarks:Mr.R.Bertrand:

The first issue to be resolved is the system accuracy requirement,exactly what level of precision is really needed for the vessel to safely accomplish its task.The next issue is to examine what specific technology can deliver the needed accuracy.Candidate technologies might include:active transponders,passive transponders,Loran-C or Global Positioning System with or without differential corrections,indeed the number of permutations and combinations becomes very large.

Another area of interest which has arisen in the last few years is the display technology and the operation of the system .This would include the hardware and computer interfaces with radar and other ships systems and the software e.g. pattern recognition and a lot of interesting

developments in software such as expert systems and artificial intelligence.The final issue which must be addressed is the vessel maneuvering characteristics;what can the vessel do if we find a way to significantly improve navigation accuracy.

We must realize that the original focus in precise navigation was on the requirements for blind navigation through the narrow channels of the St.Lawrence Seaway. As will become obvious ,and we hope to have some people address the topic,the technology has much wider application including:Arctic navigation and port access.Many systems have already been deployed,some in Canada many abroad.

There are two important questions which must be answered.These are:how accurate and reliable must any such system be? what are the various alternatives?

We should then consider this workshop to be a report on how well we have answered these questions to date and an opportunity to focus our minds on where the future opportunities lie,where our research priorities should be.Since the agenda is heavy we should proceed with our next speaker.

OPERATIONAL REQUIREMENTS

Shipper Requirements in the Seaway
Capt. McDowall,Algoma Central Railway,Marine Division

Algoma,at present,operates a fleet of 18 ships, 17 of which are principally Seaway ships. The 18th is a coastal ship and,surprisingly,the only one having anything resembling a precise navigation system.I should like to address the problem of shipper requirements in the Seaway or navigational problems in the Seaway in fog or in early or late seasonal operations.

I will endeavor to give an overview of problems we face in transiting the Seaway at present and within the context of precise navigation systems.First and foremost we must be aware that it costs approximately twelve thousand dollars per day to operate a 730 foot self unloader.Consider such a ship loading grain in Thunder Bay bound for Port Cartier Quebec and assume the ship returns to Thunder Bay in ballast,which is the norm today rather than the exception.The round trip takes thirteen days and operational costs will amount to $156,000 to which must be added $17,000 for Seaway tolls, lock fees and compulsory pilotage giving an overall total of $173,000. A reasonable assumption on freight earned would be $250,000 so what we have left is $77,000 before depreciation and taxes. Six point five days lost for whatever reason on a voyage such as I have just described rapidly turns black ink to red or profit to loss. The other side of the coin,of course,is the cumulative effect of lost time which could translate to one or more fewer voyages in the season and the monetary losses associated with this.

There is no need to remind you how fragile the Seaway is,how susceptible to controllable or uncontrollable influences.I am thinking in particular of what has happened over the past few years starting with the St.Claire ice jam in April,1984,the Valleyfield and St.Louis bridge incidents,the lock 7 collapse and others.At least three ships that I know of were grounded in the Seaway in 1986 alone.All of these have contributed directly or indirectly to delays throughout the Seaway system and we haven't even touched on the weather yet.

I believe that the reason for being here today is to look at modern technology,precise navigation systems,and how they can be used to lessen the impact of some of the delays encountered in the Seaway.However,I am also sure that all of you must be aware that the greatest navigation system in the world will only be able to eliminate a fraction of those delays,because a major portion is caused by human error,equipment failure,or weather conditions that even navigation systems cannot overcome.

To illustrate what I mean,let me say that it was rather apropos that I decided to sail to Montreal on board M.V. W Sculley on the way to this meeting.She was delayed in the Welland Canal for fourteen hours because the canal was shut down due to high winds,and then lost a further twenty four hours at Massena New York because of a ship aground below Cornwall.By the time she cleared St. Lambert lock this lost time would likely be more than forty eight hours because of traffic backup.Hence my statement that navigation systems can only eliminate a fraction of the delays

In 1979 and 1980 the DMA in conjunction with Transport Canada agreed to fund research into PRANS with the view of possibly extending the navigation season if PRANS became a viable proposition.On the technological side the intervening years have brought about substantial changes in shipboard navigation We now have electronic charts,video disc charts GPS satellite navigation,integrated navigation systems, systems using microwave signals(whether passive or active transponders). Any one of these have a particular application in the safer navigation of ships and some are presently being used in Canada for deep water or harbor approaches.In the case of the Seaway it is my firm belief that any navigation system,however sophisticated,would only eliminate the time lost due to daylight navigation and ice conditions when floating aids have been removed(and that only in good visibility).Another stumbling block would be the Montreal to Escoumin compulsory pilotage section if ,in the considered opinion of the pilot, daylight navigation only was permissible regardless of navigation systems.In the actual Seaway between Cape Vincent and Montreal the ship captains do the majority of the piloting so,when they became familiar with the precise navigation system on board the ships then that would eliminate time lost due to floating aids being removed for ice conditions.

As far as fog is concerned or any precipitation that would cause zero or near zero visibility I cannot conceive of any navigation system that will overcome lost time in the Seaway due to zero or near zero visibility.One has only to consider the ship I just mentioned that ran aground below Cornwall on Tuesday morning.From the time she left Snell lock until she ran aground, that ship made approximately twenty alterations of course in a space of four to five miles within a channel width of about 750 feet with a five knot current behind her at times.Some of those alterations were as much as 45 degrees.Technology,I am sure can give us a navigation system that will guarantee a ships position to plus or minus ten feet but can technology guarantee total reliability,guarantee that a ships master will ever fly blind under circumstances such as I have just described.I think not because much of the Seaway navigation is by sight and feel. Masters and Pilots are already reacting to ship movement even before the fractional tick of a gyrocompass but this reaction is only enhanced by the fact that you can see.

It is my opinion that,although technology will prove that it is possible to have a navigation system that will allow the ships to do all the things that you say it should do or can do,a major stumbling block will be overcoming a masters fear of blind navigation.Not to say that this fear will never be overcome but there is a vast difference between sailing a ship in a Seaway system in dense fog and flying an aircraft into an International airport in dense fog.

In the event that what we have assembled here today to discuss becomes reality, let me say that, whatever system is chosen,I believe that it should be a system that is independent of radar or active or passive transponders.I express this opinion because a lot of radars are less than reliable in precipitation and because much of the land adjoining the Seaway system is owned by individuals who might resent the placement of navigation aids on their land.

Finally, the intervening years between 1980 and 1986 have shown a decline in DMA ships from 176 to 136 ships a drop of some 22% and a decline of cargo tonnage carried of almost 25%.These statistics prompt me to suggest that extended navigation seasons and precise navigation systems are furthest from the minds of DMA directors in 1986.Now is the time of survival,survival of the fittest ,and each and every one of them is probably more concerned with the costs that can be cut in order that they can stay in business.

Ship Maneuvering Characteristics.
A.Kendrick, German and Milne.

Although somewhat superficial this presentation will address the maneuvering characteristics of ships in a manner that I hope will be understandable to someone who does not know ships well.To start I should like to discuss navigation.At its simplest navigation is the process of getting from point A to point B.To do this you have to be able to locate point A with respect to point B and the positions of any points in between which might cause you difficulty getting there.You must know,at any given instant what your own position is with sufficient accuracy to be able to avoid local hazards and to set yourself up to meet any which are coming up in the future.This description can apply to any form of movement from walking along a crowded sidewalk to flying to the moon but the level of sophistication of the processes which are involved and of the artificial aids which we are going to require depend on the characteristics of the moving system and the characteristics of the environment through which it moves.I wish to present some of the characteristics of the ships which are being considered for the implementation of precise navigation systems to define what the capabilities of the systems must be.

A navigation system must have adequate accuracy,adequate update frequency and adequate range.Capt. Fisher will be discussing the accuracy requirements in a few minutes but the update frequency should be related to the speed of motion and to the possible rates of change of those motions as well as the system accuracy.The range or the extent of display of the navigation system should take account of the ships ability to respond.The operator must have sufficient warning of maneuvering requirements to initiate any actions which he takes in good time.

One of the important facts about ships is that they are enormously fragile in comparison with their surroundings.Despite their appearance of monumental solidity ships are huge eggs.Response to rapid inputs is terribly slow.The financial consequences of poor judgement with respect to these "sluggish eggs " is likely to be severe.Ships, therefore require a very high degree of reliability and of confidence in the navigation system.

Guidance systems likewise require a high degree of reliability and confidence.Navigation systems give a level of positional information,guidance systems make use of that information.In most ships the guidance system is in fact the Master or the Pilot.The human brain is generally very good at navigation and guidance though it does make mistakes on occasion.

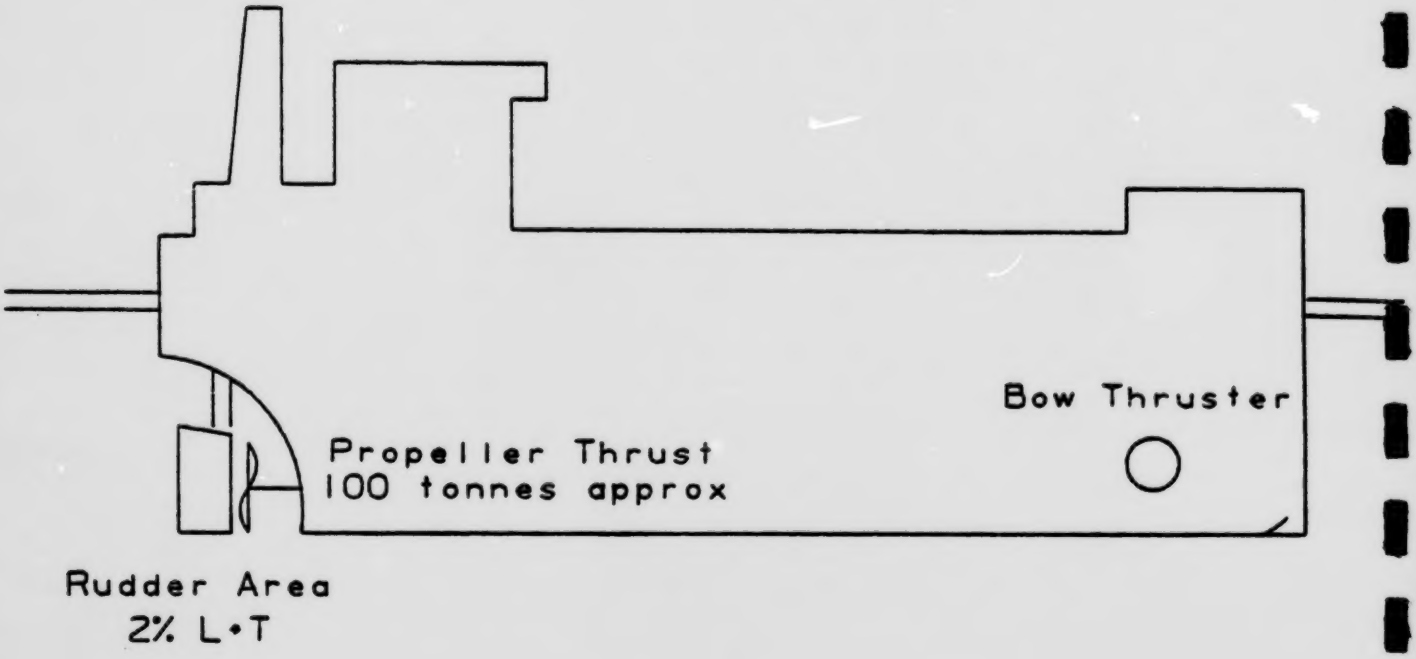
The characteristic of the ship most relevant to navigation is that it moves.Relative to its size however,it moves rather slowly.The types of ships we are principally concerned with today are up to about 300 meters in length

and they move at speeds of around five meters per second.This means that it takes a ship roughly a minute to travel its own length a pace that any self respecting snail could beat with ease.The factor that greatly increases the complexity of maneuvering of ships is that they are very limited in their capability to change either their speed or direction of motion.

Let us consider a crude representation of a ship(Fig.1) to see why this might be so.This is a representative 35,000 ton bulk carrier,a lake boat.It has an installed power of about 10,000 horsepower i.e.7500 kilowatts and generates a thrust of about 100 ton through its propeller.This thrust will allow the ship to accelerate at a rate of about one thirty fifth of a meter per second squared(not very fast). At higher speeds where the propeller thrust is less and the resistance to motion is greater then the acceleration will be even slower than that.Deceleration can be a little faster since the resistance of the water is working for you but if you try to reverse the thrust of the propeller then at some speed you will lose directional control.

Controlled speed reduction is therefore a lengthy process.Bringing this ship to a controlled stop from a speed of ten or twelve knots is likely to take five minutes and the ship will travel more than a kilometer in that time.Now, the engines and the propeller control the straight line characteristics of the ship.The overall shape of the hull,the steering gear and to some extent aids such as bow thrusters,will determine how much control can be exercised over the course.This ship has a very box like hull which is designed to maximize the amount of cargo which can be carried within a given length breadth and depth.The nature of the flow around this and similar ships means that they are marginally directionally stable under most conditions.This means that it is relatively easy for a small force such as provided by a rudder to help them change direction but it accounts for their directional instability when you try to stop them rapidly.

The rudder area of a ship like this is typically only a small fraction of the projected area of the hull.Somewhat surprisingly its characteristics are not regulated by the majority of national or international agencies or classification societies.On average the rudder will have a projected area of some two percent of the projected area of the hull.The rudder will be directable to thirty five or forty degrees either to port or starboard with a hard over command taking less than than half a minute to execute.This rudder functions as a control surface partly to provide a direct side force and partly to modify the flow around the hull in such away that the hull itself provides a turning moment.After you apply a rudder angle there is a somewhat complicated transient phase and a subsequent build up to a steady rate of turn which is unlikely ever to exceed one degree per second at full rudder and full speed.It can take about a minute to establish this steady turn angle from a



SHIP LENGTH, L=250m
BEAM, B=25m
DRAUGHT, T=7m

FIGURE 1:SCHEMATIC REPRESENTATION OF A SHIP

straight ahead condition and over twice as long to try to reverse the direction of the turn.

The turning radius of this type of ship doesn't depend very much on its ahead speed.It depends very significantly on the depth of water.If you look at the top of figure two the effect of shallow water(and shallow water is typical of the Seaway)is to increase the effective turning circle by a factor of two or more.Other aspects of maneuvering are also slowed down.If we consider a few of the other factors which will influence the maneuvering performance of the ship then two which come to mind are wind and current. Wind forces on a ship can be greater than the thrust which is exerted by its propeller Not generally in the ahead direction but certainly if you have a wind on the beam it can be a greater thrust than the propeller and this is one of the reasons why it becomes difficult or impossible to navigate in the Seaway in high winds.

Another influence is the current which can move the ship bodily by a certain distance and of course as a ship comes into a current the bow or the stern will swing at a different rate which will throw the heading off.The net result of all this is that you have a system with a characteristic speed of say 6 meters per second an acceleration of perhaps 0.03 meters per second squared,An angular velocity of up to 0.5 of a degree per second.An angular acceleration of 0.05 of a degree per second squared.Things are not happening terribly fast with these ships.Figure 5 shows these force vectors.

All these figures are for purely illustrative purposes and there is a great deal of variation in all this.If for example,you look at the scatter in turning circles,for ships presently in service (fig.3).This is a plot drawn from a report to the US Coast Guard which some of you will recognize.As you can see there are good ships and some pretty poor ships out there as well.Some of the factors which influence the performance of ships are,how much rudder they've got,what type of rudder they've got,where the rudder is positioned with regard to the propeller.Just for illustration I have curves(fig.4)which show the difference between a single rudder in a normal configuration and all sorts of fancy devices that are not generally fitted to large cargo ships such as,kitchen rudders ,cort nozzles,(which you do occasionally find)and rotating cylinder rudders.The majority of the ships we are talking about however,use the outside curve.

If you look at a ship at any given moment,where will it be in a minutes time?If you take the bows of the ship being at a given point,in a minute it can have gone (if it were travelling at say 10 knots)it may have gone as far as 300 meters or,by deceleration perhaps only 180 meters.It may have started to turn.If it has started to turn,and turned hard it may have moved 50 meters off track and have developed a change of heading of up to 20 degrees.Thus we

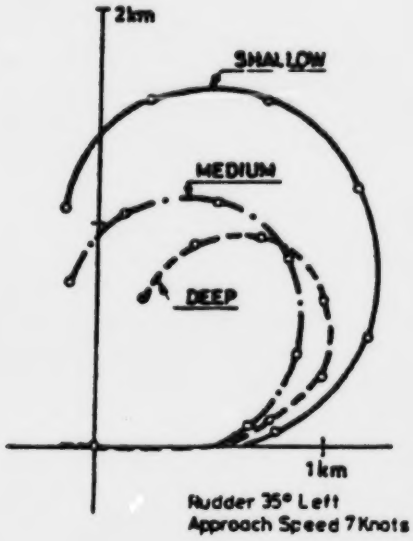


FIGURE 2: WATER DEPTH EFFECT ON TURNING

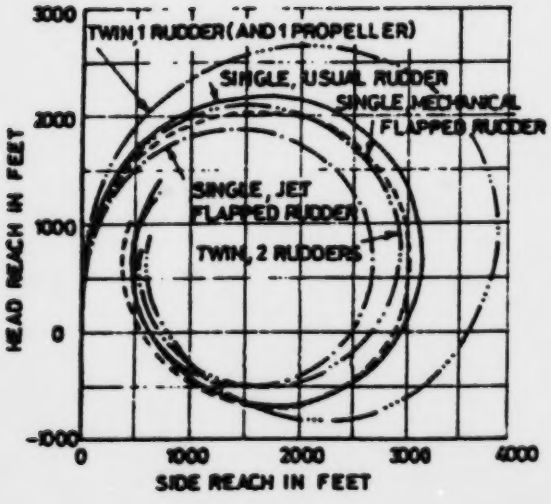


FIGURE 3: IMPACT OF CHANGING PROPULSION ON SHIPS PATHS

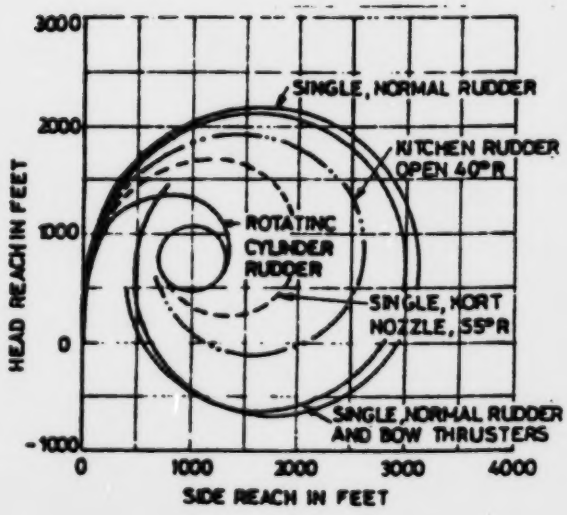


FIGURE 4: IMPACT OF CHANGING THE RUDDER ON SHIPS COURSE

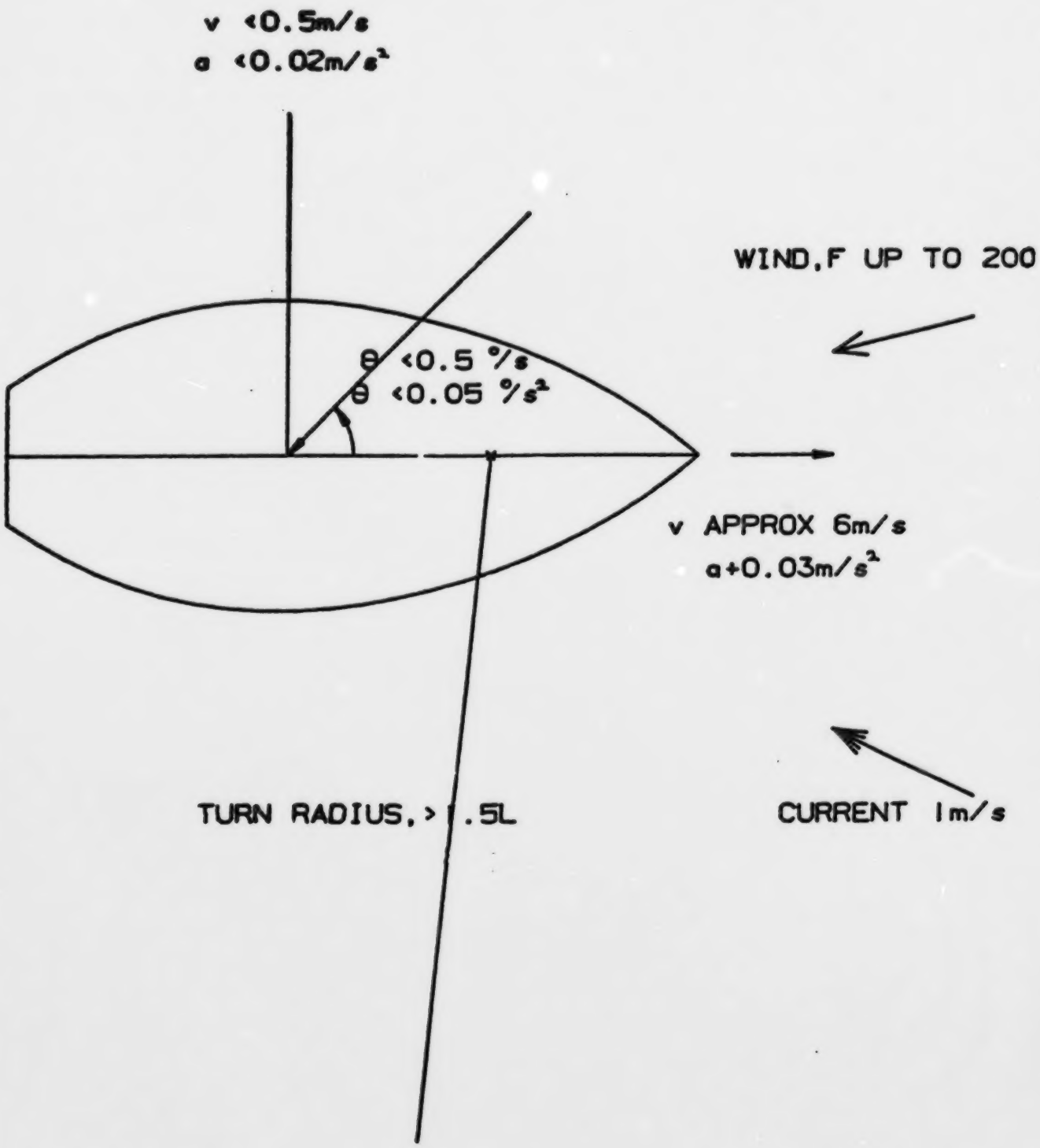


FIGURE 5: VECTOR DIAGRAM, FORCES ACTING ON A SHIP

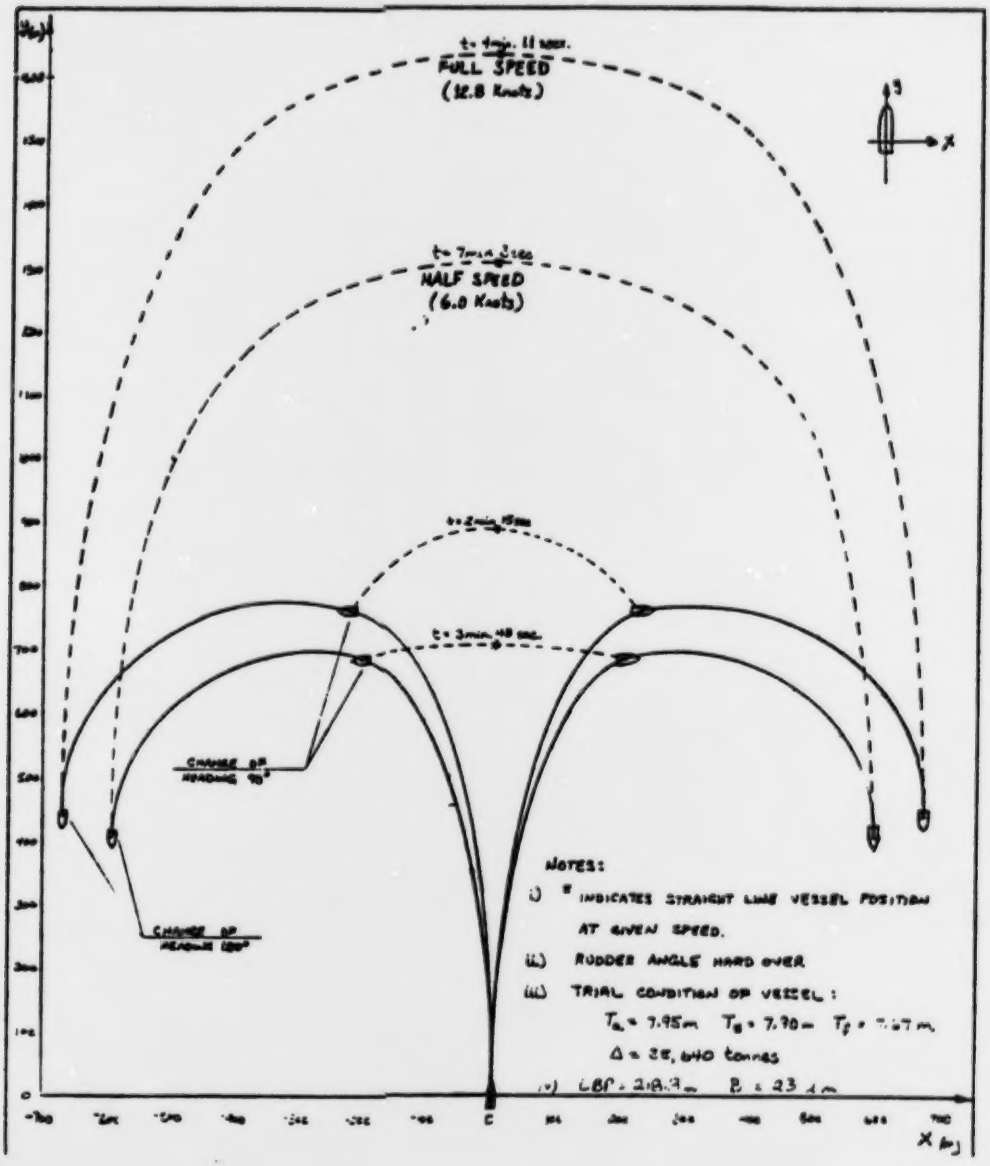


FIGURE 6: LOCUS OF SHIP'S POSITIONS

have a locus of positions beyond which the ship cannot be(fig.6).This is why turns cannot be too tight.After another minute the locus has expanded further.

This has been a very brief view of what ships will and will not do.

Shipper Requirements in the Arctic
M. Luce Vice President Canarctic Shipping

I should like to give you a very brief overview of what we see as the operational requirements for precise navigation in arctic shipping perhaps in the context of our own operation in the Arctic with the M.V. Arctic. In terms of port requirements I think the requirement falls into two different categories. There are a number of established ports in the arctic which really do not lend themselves very well to large vessels.Two good examples of that are Rae Point and Resolute Bay.To look at Resolute as an example consider the extract of the chart for Resolute Bay(fig.7).Note the tank farm for which you lie off using a floating hose and the dock for most of the general cargo which is up in this corner.We have been looking at the potential of Resolute for our shipments of oil into it because as you know we have a contract for shipment of oil out of Bent Horn and we are looking to Resolute as a potential terminal site.

The conventional route into Resolute is a straight line shallow draft route which comes in right through the shoals.There is a deep draft route which comes in through a dog leg into the oil terminal.Neither of these routes is suitable for the M.V.Arctic.The shoal areas here are too shallow for the Arctic and there is too narrow a gap.We are examining a route which is quite tortuous, as you can see from the chart.We do not know as yet whether the route is feasible.It is a route that we will be evaluating to see if it is sufficiently safe to consider seriously .If it is it will obviously need some fairly precise navigation equipment to tell us where the ship is lying across the channel and its position as it progresses until it starts to pick up a valid leading line.This is an example of trying to cope with an existing terminal which was not originally intended for large ships.

Other terminals such as the newer terminal at Bent Horn are such that they have deep water up to a straight line shore and are such that we take the Arctic straight in to about forty feet of the shoreline and either sit her in the ice or at anchor.There is no need of anything more than a single leading line we have actually experimented with a precise navigation system at Bent Horn and found that it added very little if any safety to the operation.

One of the other terminal sites which is established and where we have had problems in terms of keeping track of the ships position is Rae Point(what the future of Rae Point itself is in the present oil climate,we're not sure).This is a very rough plan of the Rae Point harbor(fig.8).As you can see there is a normal leading line in and as you can see the ship is very confined in this harbor particularly around the shoal areas.We did experiment here with a precise navigation system in 1985,the Offshore Surveys system,(the

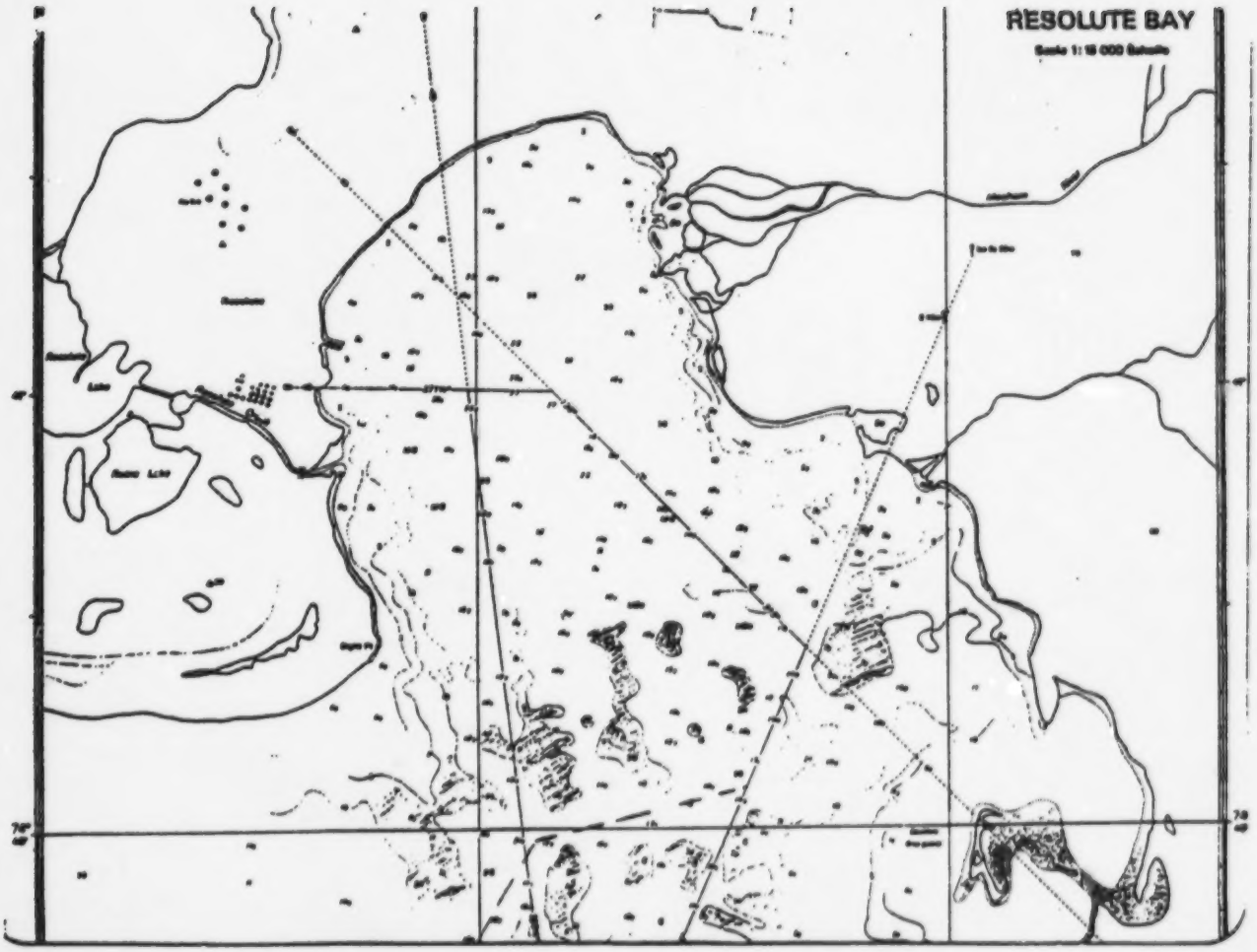


FIGURE 7:ENTRY TO RESOLUTE BAY

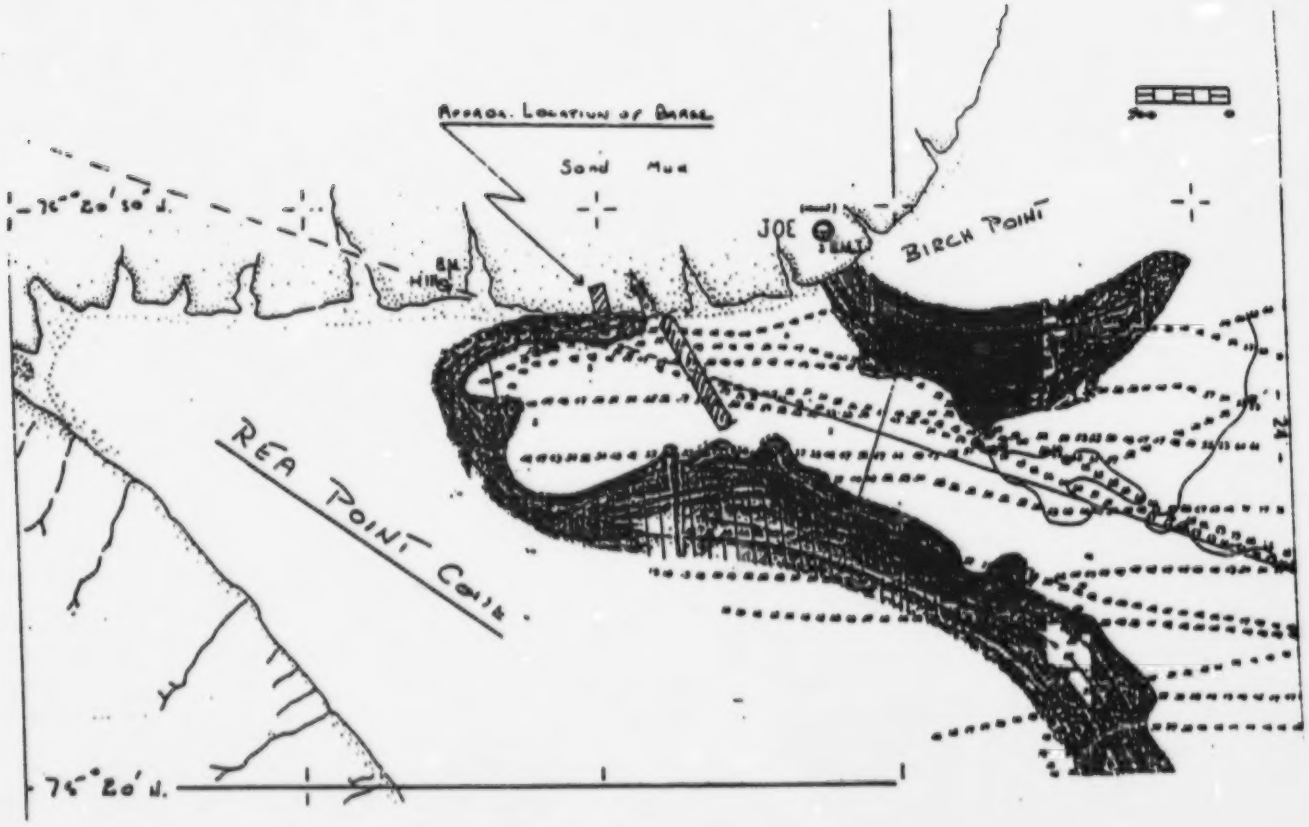


FIGURE 8:RAE POINT HARBOR

company is based in Vancouver).We found it was quite valuable particularly when the ship started to get off the leading line.The benefit of the precise navigation system was to give us a fix on the ships position as to how far she was off the leading line.Without buoys and with ice around which eliminates the possibility of putting buoys in to tell you where the shoals are you need something which tells you the position of the ship in relation to the leading lines.We found the precise navigation system to be particularly effective here although the actual installation could have been improved.

Our requirement then is for precise navigation into established ports and terminals such as Resolute and Rae Point .If we are establishing new terminals or if we are working with operators or producers who are going to establish new terminals it is our feeling that these sites will be chosen to accept the kinds of ships we are dealing with.

In terms of our other requirement,we now have a class four ship and what we are focussing on is the potential for new markets and new trades for that ship. One of the strategies we are looking at in Canarctic is the potential for opening up trade between the Eastern Arctic and the West and possibly the Far East.We are talking to existing customers in that vein and there is some interest.We foresee that there may be a need to look at trade from the Eastern Arctic to the Far East through the North West Passage.This area in particular is not well surveyed,it is quite shoaled in places and the route is quite tortuous.This is an area where we are looking at a precise navigation system,perhaps not as precise as a port system but certainly precise enough to locate the ships position with an accuracy of about ten meters.Typical of that route is the area around Jenny Lind Island(fig.9) with many shoal areas and two potential routes one North of the Island and one that goes through the south about passage.At any given point with ice in the area,with large expanses of ice,your choice of route may be somewhat limited particularly if there is old ice around so it becomes important to have a navigation system around that gives you almost instantaneous position.

In this vein we have felt that we are not too keen on dealing with active transponders.Our preference has been to look for a system that will rely only on passive reflectors.We are working with the department of fisheries at this time and do have an experimental radar on the ship,a cross polarized radar that we think may have some potential for developing a passive reflector type of system.In terms of this area we have looked at the options and it seems to us that one of the options is not the normal precise navigation system we are used to thinking of but something like differential GPS.We have been investigating the potential of GPS to cover all our requirements,in the southern passage as well as Resolute.It appears from our

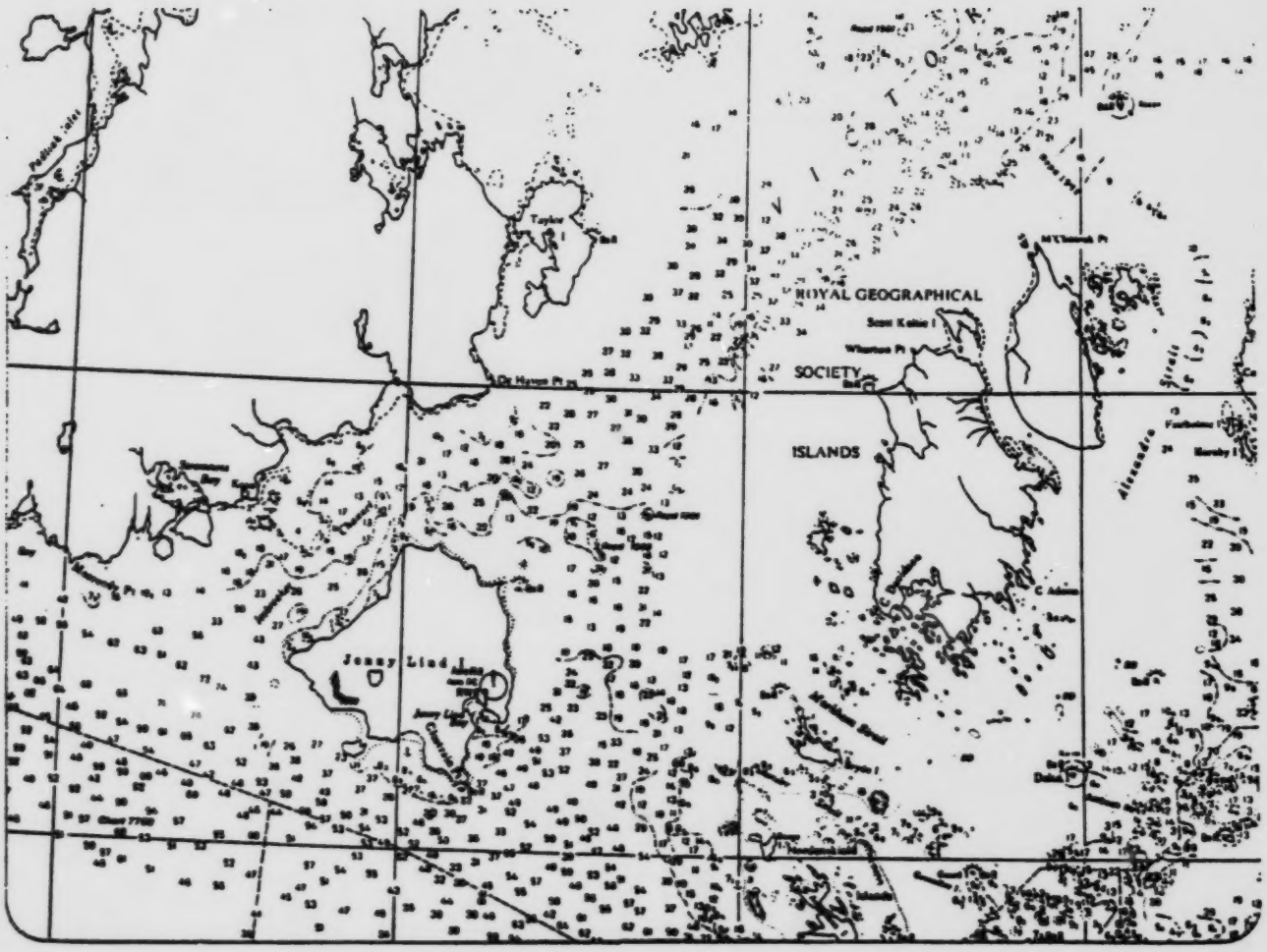


FIGURE 9:JENNY LIND ISLAND

investigation so far that with one ground station on Victoria Island that we could get coverage to a radius of about five hundred kilometers.This would in fact give us ten meter accuracy throughout this entire area.Thus we are starting to look away from the localized precision navigation systems to something more in the vein of a differential GPS that would provide area coverage.If we were to put systems all through the passage it would get quite expensive.

Mr. Bertrand invited descriptions of other users requirements and systems from the floor

Comment:Mr.D. Williams:Marine Atlantic:

We have an operational system which cost us some $250,000.We acquired the system from Offshore Systems Ltd. about a year and a half ago.It has been fully operational since June,1986,although we really haven't been able to make full use of it until the new ship came in.We had two to three weeks when the shore transponders gave quite a few hiccups.We found that the system needs redundancy given the performance to date.The operations people are quite happy with system now and say they would like it on another ship.If you watch the Masters carefully you will notice that every four or five seconds he is glancing at the screen and is utilizing the information.In their mind it is the picture that matters numerical displays are not considered important nor are vectors or other such displays.

There was always concern whether the ship equipment would break down but in looking at the reliabilities and the occurrence of critical weather the probability of failure under critical conditions is about once every hundred years.We operate into a very confined harbor at Port Au Basques and the ship has to make a 180 degree turn in order to dock so we don't want the Master committing himself to relying on the equipment in a condition where he would otherwise not have made the decision to enter harbor.

The Masters are not yet prepared to dock the ship in a thirty knot wind in a blinding snowstorm using only the precise navigation system but as confidence builds the day may yet come.They are certainly prepared to dock it much more quickly blind in fog.Speed is not our primary concern, safety is.

We have been working on this problem for two to three years now and my warning to others is,don't underestimate the operational problems even if you have the technology solved.There are a hundred and one things that can go wrong.For example I must have talked to 50 people about gyro interfaces and every one said,"oh! that's easy".I have yet to meet the man who can actually do it perfectly something always goes wrong.Software in particular requires a long time to ensure its proper operation.

Question:Mr.A Kendrick:

As far as a thirty knot wind and blinding snowstorm are concerned the Masters would not even consider entry if the wind exceeded say forty knots,even if they had unlimited visibility.So are we not getting to other limits on the Masters that any equipment is incapable of solving?

Reply:Mr D.Williams:

Yes you are quite right but it is interesting to note that although the Masters have two displays already on the bridge they are asking me for another.That,I think,is an indication of how keen they are about using the system.Not to say that they are ever going to put blackout around the windows and just rely on the system.

Comment: Mr.Luce:

Dave has raised a very good point:it is obviously very applicable to a ferry operation where you are going in and out every day but when you only get to use that type of system once a year and particularly when you are dealing with a harsh environment like the Arctic you have an entirely different type of operational requirement altogether.So if I have sounded a little bit negative toward transponder types of systems it's because we,in Canarctic have a totally different operation.

Reply: Mr.Williams:

I am also interested in Marine Atlantic's Labrador operations.We have had three groundings this year.Some of them are obviously human error but the Masters have a very difficult job.If you are going into one port or operating in the Seaway and you have the radar images stored in your mind and you know the area it's one thing but if you're going up that coast of Labrador which is not well charted anyway then I think that anything up there would be better than nothing.

Question: Mr.Rudback:

Capt. MacDowall talked about the Seaway requirement without very much notice and I note that we have not talked very much about the river I wonder if might extend your discussion into a consideration of the river itself.Are the conditions essentially the same or are the restrictions relaxed or is it totally dominated by the pilotage question.

Reply: Capt.MacDowall:

I don't know whether it is dominated by the pilotage question I would say the that the navigational requirements

from the point of view of a Pilot or a Master are not quite so severe as they are in the Seaway.I would say that the most difficult stretch would be that area around Three Rivers and Sorel.I would say that from Three Rivers down to Escoumin there is some tricky navigation but I don't think it is as severe as in most of the Seaway.I would think that about eighty percent of the river from Montreal down to Escoumin would lend itself more to improvement by precise navigation than the Seaway would.

Comment: Mr.Bertrand:

I would suggest that one way of describing the differences would be to say that to ensure safe navigation one would have to call upon different levels of accuracy in different parts of the Seaway.All of which leads us to our next speaker.

Accuracy Requirements:
Capt. E.T.Fisher; German & Milne:

As I am in front of a few of my peers I shall have to be very careful here.Any technical points will be taken up by Andrew Kendrick.At the beginning of our study or at least when I started working on the project an accuracy requirement of ten feet was the cry.The program that was carried out on the PRANS system developed by Associated Controls established the requirement as being ten feet i.e. plus or minus three meters.This requirement was confirmed by DMA Masters and Canadian Coast Guard as being adequate.I quite agree it certainly would be.However as the project progressed particularly the investigations of the Communications Laboratory at McMaster University the question continually kept being raised;why ten feet?Ten feet would be prohibitively expensive from a technological stand point ; couldn't the requirements be relaxed?The only answer as to why the requirement had been stated as ten feet appeared to be that the original ACCI proposal had claimed ten feet accuracy and no one had seen fit to question the requirement thereafter.

This requirement bears no relationship to any thing Mr. Kendrick said with respect to ships.The requirement had obviously not been looked at by anyone but electronics designers.What we really required was some determination of a maximum permissible error that would permit a ship,in theory at least to maneuver through given reaches.In order to do that it was necessary to examine the maneuvering characteristics of a typical ship and all the forces affecting it in a channel.We have no documentary evidence indicating that any such examination was made to determine the statement of the ten foot error and reading very large studies such as those done in the U.S.for the Panama Canal there is no evidence that they have taken maneuvering factors into consideration either.No one seems to have

related ships performance to operational requirements for navigation accuracy before.

So in 1985 German & Milne were given the task of assessing the Seaway.The results,you have before you in "Montreal to Kingston Section Definition of Accuracy and Display Requirements".Basically what we did was take a look at the Seaway from Montreal to Kingston and examined every reach from the standpoint of those navigational requirements in it that required changes of course or maneuvers that might cause problems.There are 183 reaches between the two points.Every reach has a turn going in and a turn coming out.Some of those turns are 5 degrees and some are 45 degrees.If the length of a reach is 1 mile and it has a sharp turn on the entry then the ship will just be getting settled on its new course when it has to make the next maneuver.This increases the degree of difficulty for the Master and affects the decision time he has.The amount of time the Master has to make a decision is quite short indeed you could almost relate it to the speed of decision making in aircraft.

There are specific points where a decision must be made and executed.If you are two or three minutes late in making that decision and executing it you are going to be in trouble.We examined the charts and looked at how much of the Seaway could be navigated by radar in fog.There are a lot of very varying conditions all the way up the river.Strangely enough it turns out that the first twenty one mile reach through a three hundred foot channel can easily be negotiated by radar,because it's like driving down the highway(you stay in the middle and go through).There are other reaches like those in the middle of lakes where you have low lying land and the radar return simply cannot be interpreted to any degree of accuracy.As the water level changes or seasonal changes occur due to vegetation growing the radar picture also changes leading to inaccuracies of interpretation.

In some places it is possible to use radar (assuming we have a well trained radar operator and navigator)

From our examination of the reaches and consultation with Mr. Kroon of the Seaway Authority and several ships Masters we determined the critical reaches.It is interesting to note that the very experienced captains never look at a chart or radar in the entire 183 miles of Seaway.They know by heart every turn, every course, every buoy.They never look at a chart and that is what we are going to have to replace if we wish to automate the task.So when we think of designing a display we have to think about giving the Master all the information he presently carries in his memory.

We set the required accuracy at 25 feet.This actually wasn't determined from our studies it was an arbitrary selection of an error to look at as a maximum error and then we looked at placing the ship in the Seaway to see how much room was left for the navigator,within which he can make his own decisions .You can't determine for him in advance

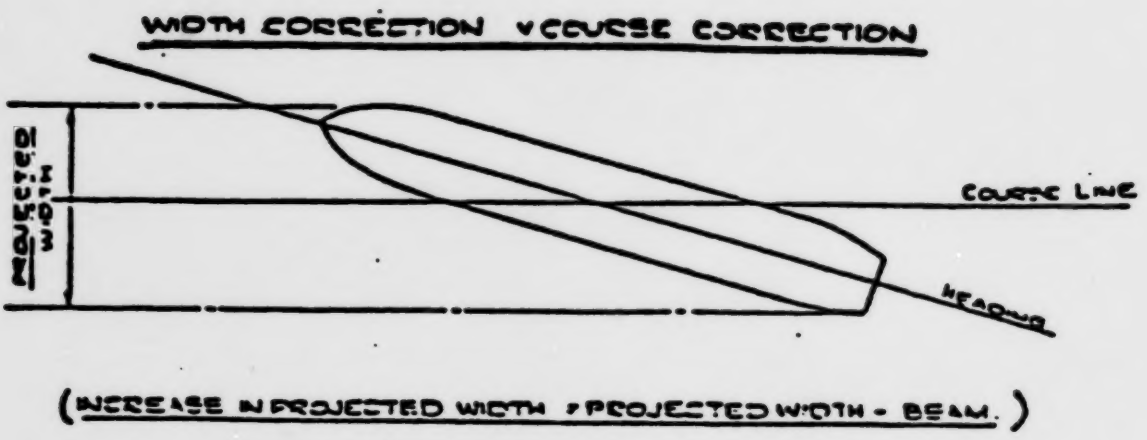
what line he must take in negotiating every corner that has to be his decision based on the characteristics of the ship and the conditions he is operating under at the time.The 25 feet seemed a more reasonable maximum.For one thing it more closely approximated the state of the art in systems that could reasonably be expected to do the job.It also related well to studies that the Seaway authority had done relating to total error budget.

When you get down to the final analysis, error budget comes down to error in the system plus the effective breadth of the ship because the ship doesn't necessarily go directly up the channel.If he has set and drift with wind and current affecting him he must crab up the channel and you have to allow for this.This slide (fig10)shows the increase in his effective width due to crab.The effective width then of course varies with the length and beam of the ship.Thus the system error and the increase in effective width are the error budget we have to consider.

Within the area which we studied,reach 25,26,and27 in the vicinity of Cornwall turned out to be the most difficult to negotiate in the Seaway.There is a 450 foot wide channel with a 43 degree turn in it(fig.11) then another of 45 degrees but a little easier.It is this type of channel that would be the ideal test for a prototype precise navigation system.This concept was supported by the captains who had knowledge of the Seaway.

We looked at a ship in a 450 foot channel(fig12).In other words a maximum sized lake bulk carrier 730 foot in length with a beam of 75 feet transiting the channel.He has a position error of +/- 25 feet and we looked at giving him 6 degree crab angle which would be the equivalent of five sixths of a knot set at 90 degrees to the course angle with the ships speed at 8.5 knots.Now if he were in fact navigating blind or going without buoys then he would not be travelling at that speed;which is in fact the speed limit for this section of the Seaway.If however,he slows down then his crab angle will increase.Thus weather and current become the limiting factors.

We wanted to find out how much room he would have between the extremities of the ship and the side if the channel. This turns out to be half the channel width minus the position error plus half the beam effective.The dotted line shows the error if it were to the right of the course line and the actual ship outline shows what it would be if the error was to the left.He would have 125 foot clearance from the side of the channel both bow and stern in this situation.The question is,if the captain has this kind of clearance would he feel comfortable?I.e.is there room for maneuver? We asked the question if that was the case and if that information were presented to the captain then could he indeed maneuver his ship? Thus if the ships maneuvering characteristics as discussed by Mr.Kendrick were to be taken into account would the captain have sufficient safe clearance.



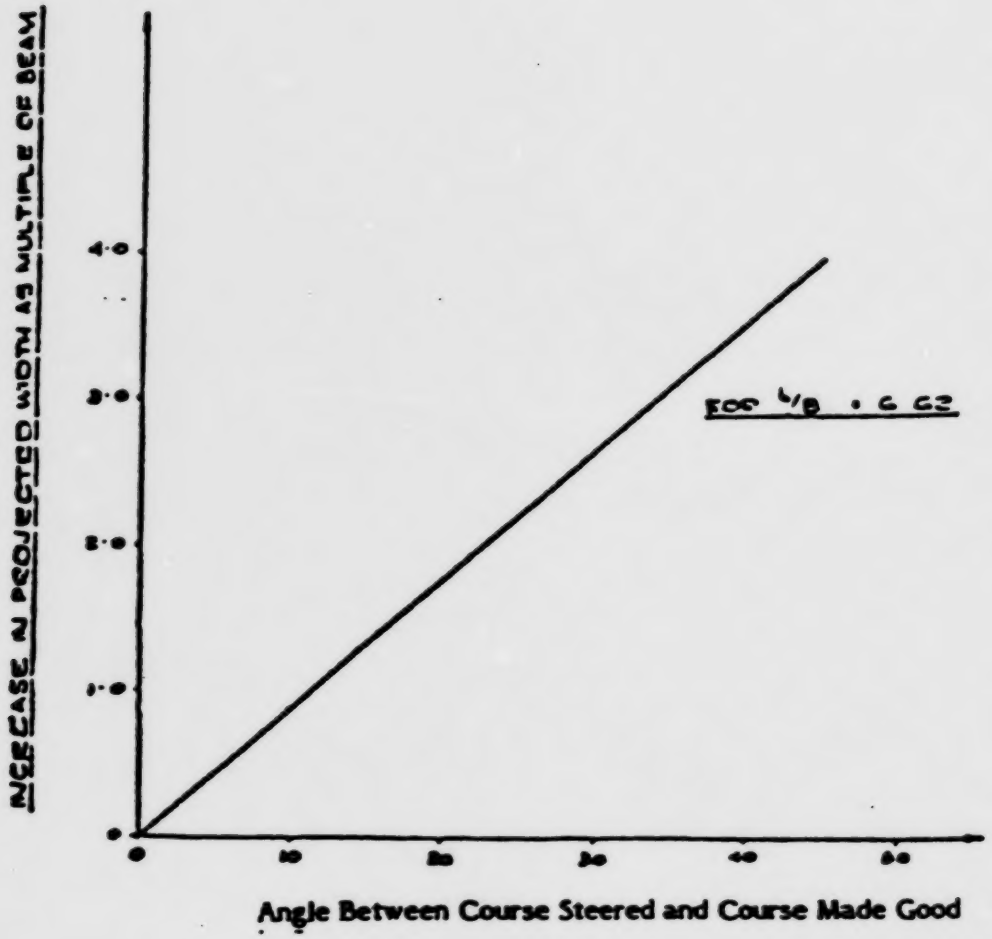


FIGURE 10: INCREASE IN SHIPS EFFECTIVE WIDTH

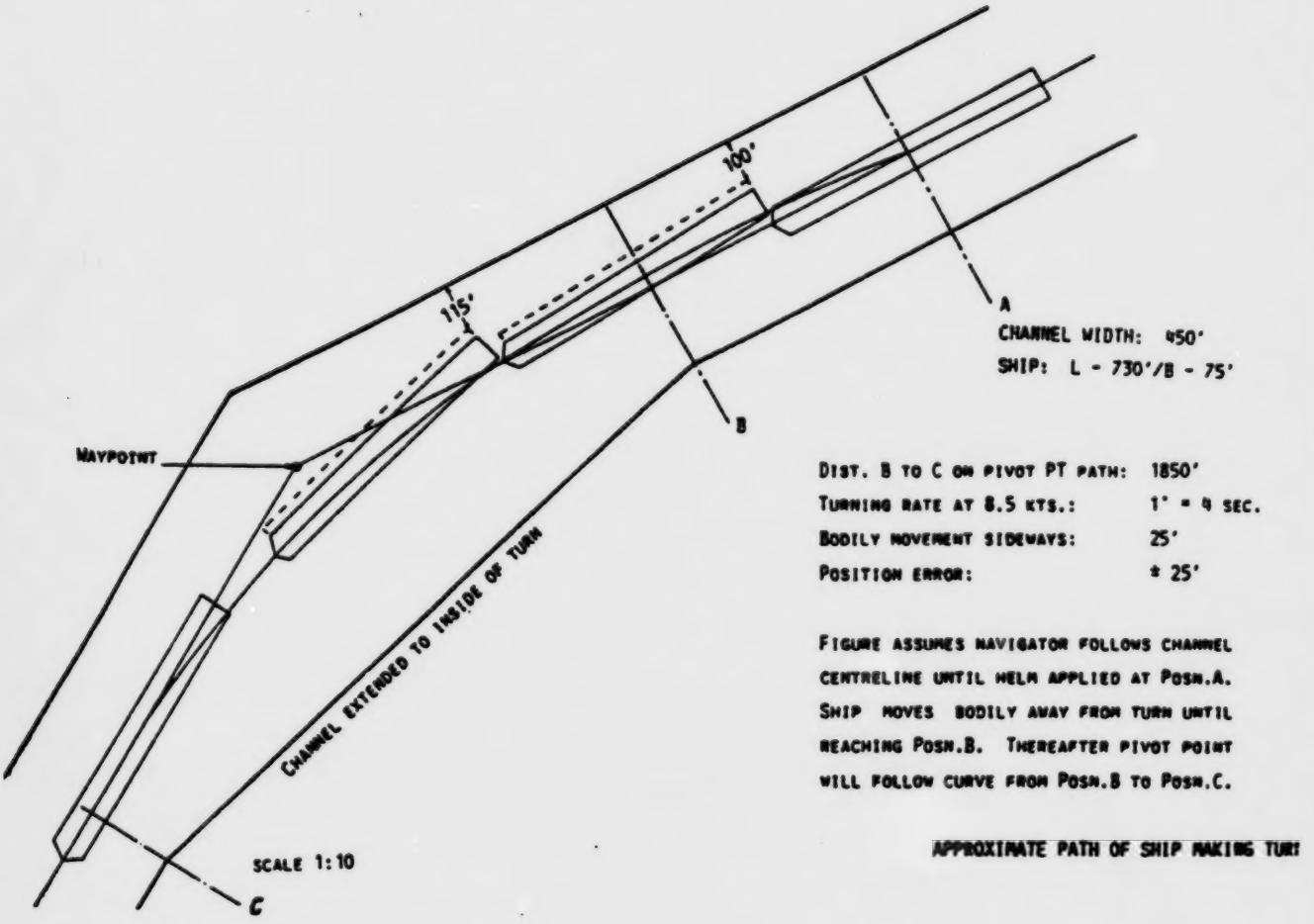
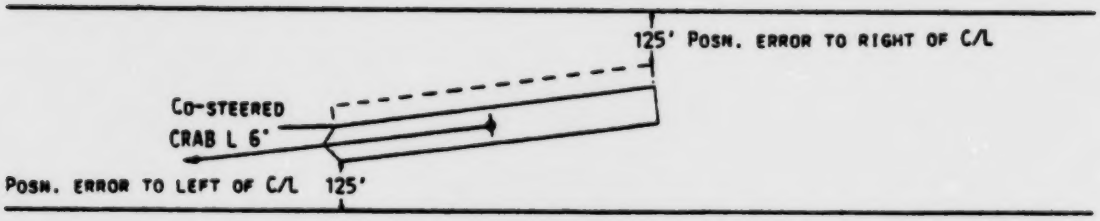

100'
115'
A
CHANNEL WIDTH: 450'
SHIP: L - 730'/B - 75'
B
WAYPOINT
DIST. B TO C ON PIVOT PT PATH: 1850'
TURNING RATE AT 8.5 KTS.: 1° = 4 SEC.
BODILY MOVEMENT SIDEWAYS: 25'
POSITION ERROR: ± 25'
FIGURE ASSUMES NAVIGATOR FOLLOWS CHANNEL CENTRELINE UNTIL HELM APPLIED AT POSN.A. SHIP MOVES BODILY AWAY FROM TURN UNTIL REACHING POSN.B. THEREAFTER PIVOT POINT WILL FOLLOW CURVE FROM POSN.B TO POSN.C.
CHANNEL EXTENDED TO INSIDE OF TURN
APPROXIMATE PATH OF SHIP MAKING TURN
SCALE 1:10
C

FIGURE 11:APPROXIMATE PATH OF SHIP MAKING TURN



SCALE 1:10

SHIP: L - 730'/B - 75'
POSITION ERROR: ± 25'
DIST. OFF = 1/2 CHANNEL WIDTH - (POSN.ERROR + 1/2 B.EFF.)
225' - (25 + 75) = 125'
NOTE: 6° CRAB L.= 5/6 KNOT SET AT 90° TO COURSE LINE
WITH SHIP'S SPEED 8.5 KTS.

FIGURE 12:SINGLE SHIP IN 450 FOOT CHANNEL

The next part we looked at was the same ship making a turn(return to fig.11) where it becomes most difficult and I should like to say right at the outset that this is not the way a captain would actually take the turn.We merely took the center line of the channel and the way point and said that he would approach along the center line and end up on the center line and it would be a continuous process.Here we get into a different set of dynamics.Here it is the pivot point which we are moving around(fig13).When the rudder is put over a ship does not does not suddenly start turning,it is not on railroad tracks.If you put the helm to port the whole ship moves bodily to the right,to starboard before it starts the turn because the area of the rudder applies a force and the inertia of the ship does not respond so it has to go sideways.So, depending on the amount of helm being used, the speed etc. the ship will quite literally to move sideways before it starts to turn.Figure 14 shows the motion and the steady state as it follows the line.Returning to figure 11 we can see the ship starting into reach 25. The line moves to the right then enters into a continuous turn along the line.It is going around the corner between reach 25 and 26 going westbound.You will note that the channel is extended to the inside of the turn and it is very probable that a ships Master would cut that corner.At 8.5 knots,if he wants to finish up at the final point he will be turning one degree every four seconds,which isn't terribly fast.He moves sideways 25 feet(actually he probably wouldn't move quite that far).Then he would have 100 foot clearance at the worst point.Then it gets to 115 and thereafter he gets back into the center of the channel.So his worst condition (if a ship did that) would be 100 feet.Insofar as he has room to come inside if he so desires then he probably could navigate this section blind using precise navigation equipment with 25 feet accuracy if he had all the information presented to him properly.

We also looked at the configuration of two ships passing.We now go from a configuration of a four hundred and fifty foot channel to a six hundred foot channel and apply those same considerations (fig 15) Both require a crab angle to overcome set and drift.Generally speaking they will both move to their own side to pass one another.What is left out here is that each ship must have the other ships position and aspect to the same accuracy as his own and this would have to be displayed with his ship. There is no way that the captain could perform this maneuver without visual understanding.Unless the two ships can interchange all this information then we will probably not attempt this maneuver blind for quite some time.

We also looked at what would be required in terms of display (this was rather minimal).We would have a display,at a minimum, of the outline of the channel(fig.16) on the display.However, the display does not translate position very accurately. In going from the position,as measured on

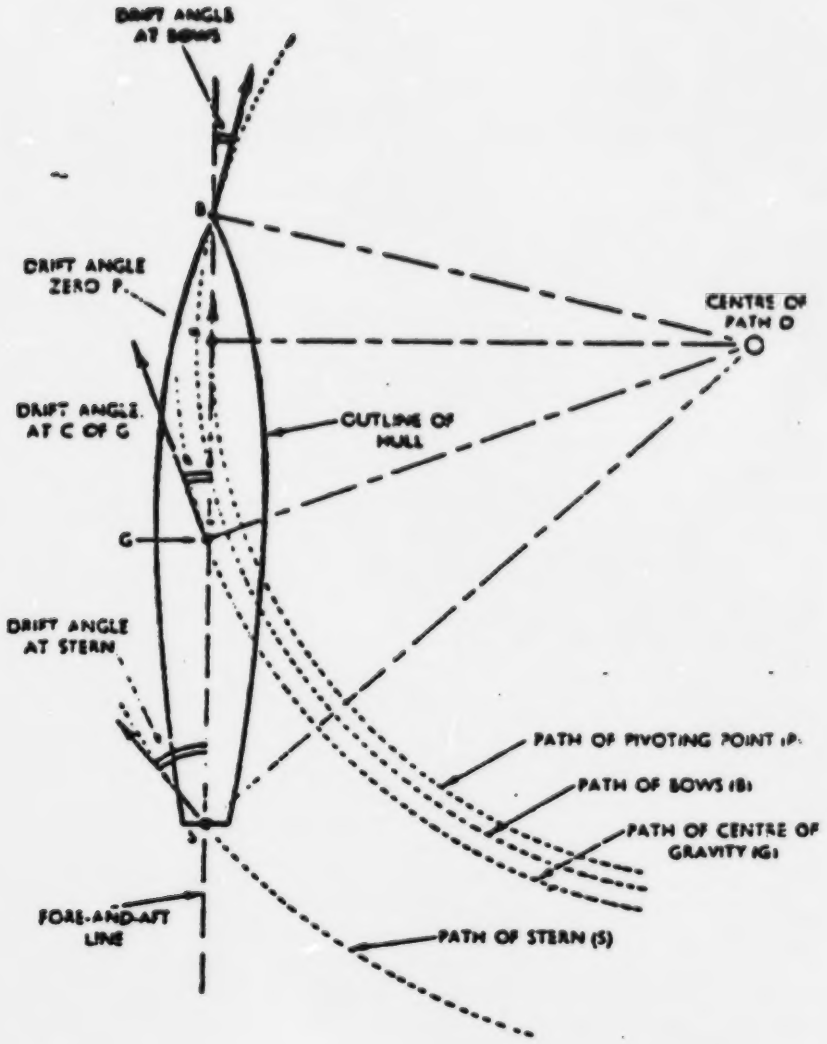


FIGURE 13: PATHS DESCRIBED BY VARIOUS PARTS OF A SHIP TURNING UNDER RUDDER WHEN STEAMING AHEAD

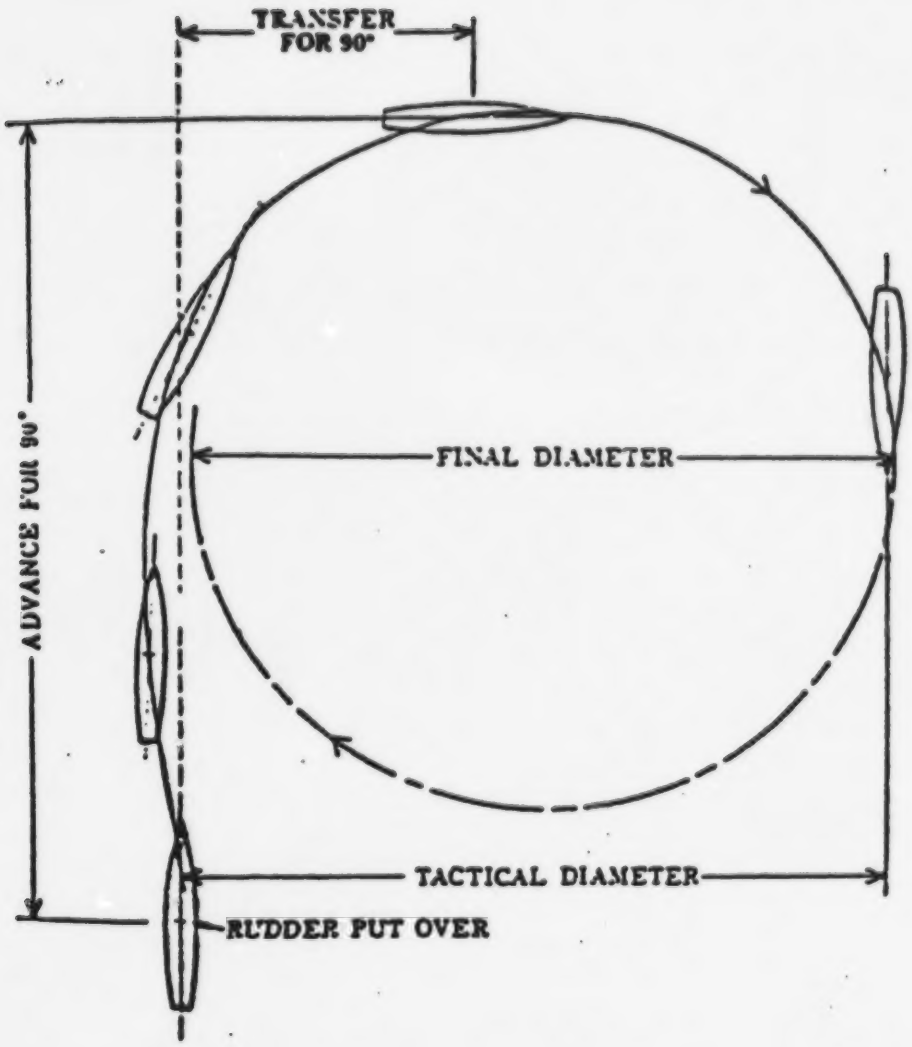
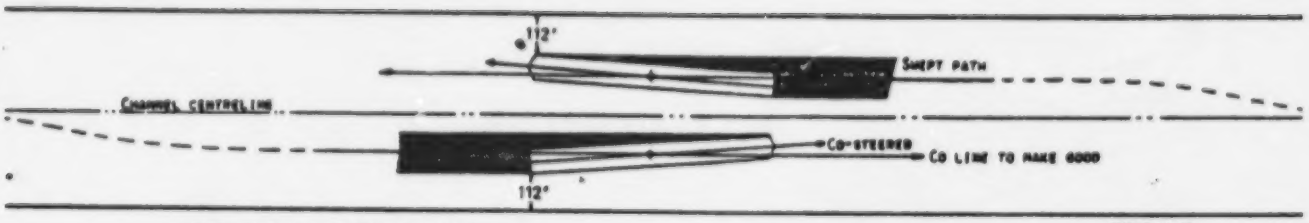


FIGURE 14: TURNING CIRCLE



DIST. CG EACH SHIP FROM CENTRELINE
POSN. ERROR + 1/2 SHIP'S BREADTH + ⁰ B.EFF.
25' + 38' + 63' = 126'

CLOSEST PART EACH SHIP TO CHANNEL LIMIT
1/2 CHANNEL WIDTH - (POSN.ERROR + 1/2 SHIP'S BREADTH + B.EFF)
300 - (25 + 38 + 125) = 112'

SHIP: L = 730'/B = 75'
CRAB L: 0'
BEAM EFF.: 125'
POSN. ERROR: ± 25'

SCALE 1:10

FIGURE 15 SHIPS PASSING IN 600 FOOT CHANNEL

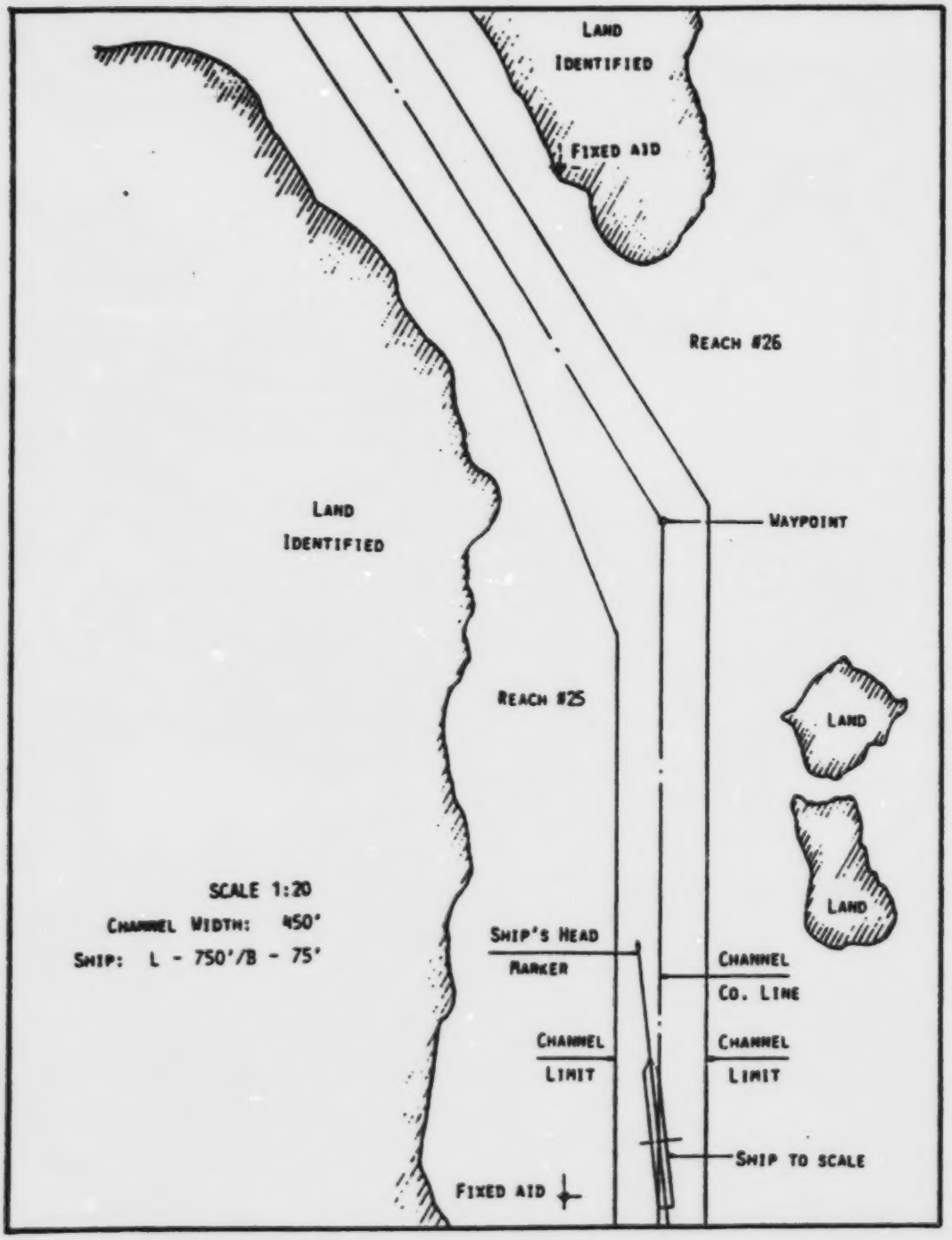


FIGURE 16:DISPLAY REQUIREMENTS

the display there is about a 15 error or one pixel. So in addition to the video display you would require digital readouts covering the absolute essential information these are listed in Table 1.

Channel course line	Degrees true
Ships head	Degrees true
Speed over ground	Knots and tenths
Distance to next way point	Miles and tenths (feet within 1mile)
Time to next way point	Minutes and tenths
Course line next reach	Degrees true
Minimum distance to channel limit	Left: in feet Right: in feet

Table 1 Digital Readouts

It is rather interesting to look at a ship making a turn and see what part of the ship actually makes the turn (returning to fig.13)If we look at this diagram we will see a point marked drift angle zero.This is the turning point of the ship,from there forward the ship is going to the right and from there aft it is going to the left.Very roughly speaking that point is one third of the distance from the bow to the center of gravity.It is the point at which if you put an accelerometer on it would not register.There are many circles based on many parts of the ship so when we talk about navigational accuracies that are turning out to be about the size of the captains cabin we have to ask where is the center of the navigational datum point? Where is it going to be? That would have to be selected.It could be the turning point.Personally I like the center of gravity because on the ships I've been on,the center of gravity is near where you are, standing on the bridge.However on a lake boat you would be standing ahead of the turning point so the decision as to where to locate the navigational datum will have to be related to the ship.

We have only been talking about instruments, the ultimate instrument I suppose will be the one that replaces the man on the bridge and makes those decisions for him either electronically or through some form of program.I am in no doubt that it can be done,if not now then some time in the near future.However,until we reach this point whatever system we use will have to be something that a ships Master can be trained into.

One of tools we can use to check out any system is a maneuvering simulator.Unfortunately we don't have one in Canada.With a simulator you can simulate the dynamics of a lake boat,put in a trial system and ask a lakes captain how the system feels.This will allow proving out the system to a much greater depth than we have.

REVIEW OF CANDIDATE TECHNOLOGIES

Introduction: Mr.R.Bertrand:

As a result of the steering committee decision some three years ago to study possible alternatives for precise navigation the TDC mandated Canadian Astronautics Ltd. to investigate the alternatives and to compare them and in short to try to put things into perspective.I am not really sure if our crystal ball is that clear but we have here this morning Mr.Raman from CAL to give a presentation on some of the candidate technologies.Later this afternoon there will be a presentation on the comparison of these technologies;their pros and cons and limitations etc.So for this morning Mr. Raman will identify the candidates.

Review of candidate technologies:
Mr. R.Raman Canadian Astronautics Limited:

(note this discussion is elaborated in TP7816E
Precise Integrated Navigation System (PINS)

I shall be discussing a study which we have recently completed on the alternatives for precise and integrated navigation systems mainly for use on the Saint Lawrence Seaway System.We have called this PINS standing for the Precise Integrated Navigation System.

The topics of discussion will include :the requirements for the system,the different alternative systems we would like to study and compare,and the preferable system which will do the job, the most cost effectively and still be technically feasible.

The first two aspects:the requirements and the alternative systems I will discuss now.Later in the afternoon session Mr. Dan Ball will discuss the selection of the system.

The objectives of this particular project were to look at the Seaway navigation in fog without any buoys or channel markers.This study was funded by the TDC and we had some assistance from Capt. Fisher in formulating the requirements.Our use of the acronym PINS comes from our interpretation of Precise meaning narrow channels and Integrated meaning integrating information taken from many sources like for example: ships location from a positioning system ships bearing from a gyrocompass and an electronic chart which would include all the navigation aids markings.A desirable feature would be to include the real time radar image onto the display.

The positional accuracy requirements were derived from Capt. Fisher's documents.Along track accuracy as taken from the German and Milne report is plus or minus twelve point eight meters. The across track accuracy is plus or minus seven point six meters and the bearing accuracy is point

five degrees.We have assumed the same values as the required dynamic accuracy of the system.That is,as the ship is moving along we require this type of accuracy.Because of system operation we were required to come up with system static accuracy requirements.We had to integrate the information from both the positioning system and the ships bearing system.Since the ship is moving we had to ensure that the static accuracy which is better is appropriately matched to the dynamic characteristics.So, including the effects of turning,of errors in the bearing we came out with the static errors allowable of eight point four meters along track and three point nine meters across track.

The importance of this derives from such factors as bearing error.For example the error in bearing of the ship reduces the clearance you have to the edge of the channel.It is not only the positional errors that are important but other system inputs too.You can read about the derivation of our accuracy figures in the report.

The additional features we would like to see is a failure alarm in eight seconds or less and a desirable approach would be to have a two second flag. If the system went out of operation then in two seconds we would have a flag in four seconds a quiet alarm and over six seconds we would sound a loud alarm.We chose these numbers on the assumption that the ship could come to a full stop in about eighty seconds.So a ten percent allowance in time should provide a reasonable amount of time to warn the captain to stop the ship.These are summarized in figure 17.

The display requirements(fig.18) include the graphic display and the digital data read out.The graphic display(fig.19) should indicate the channel course line.We assume the channel course line will be vertically up as shown in Capt. Fisher's presentation .We would overlay the ships image and the land image on the radar display.We would also indicate a fairing line showing the course history since this helps in understanding the dynamics of the ship.A zoom feature which can be varied by the operator so that he can look at the details of the image and a two second update time which is mainly conforming to the ships radar update time are also included in the display.We also recommend the use of a color display in order to be able to code up more information.

The data readout conforms to what has been given by Capt. Fisher.We have a digital readout coming out on the top which includes all the information I listed earlier.The channel course line is vertically up and the channel limits are indicated.When the ship comes to the next way point the entire picture will be turned through an angle so that the next course line will be vertically up.The coast is outlined as you can see.

In actual operation the system would give out radar points in such a manner that, if these were your error limits(fig 20)operationally of your system there could be

- POSITIONAL ACCURACY REQUIREMENT (DYNAMIC)

  ALONG TRACK: ± 12.8 M (42 FT.)

  CROSS TRACK: ± 7.6 M (25 FT.)

  BEARING : ± 0.5 DEGREE

- STATIC ACCURACY REQUIREMENT

  ALONG TRACK: ± 8.4 M

  CROSS TRACK: ± 3.9 M

- SYSTEM FAILURE REQUIREMENTS

  - SYSTEM FAILURE ALARM 8 SECONDS OR LESS
  - DESIRABLE APPROACH
    - 2 SECONDS - FLAG
    - 4 SECONDS - QUIET ALARM
    - 6 SECONDS - LOUD ALARM

FIGURE 17: SYSTEM ACCURACY AND FAILURE MODE REQUIREMENTS

- GRAPHIC DISPLAY
  - Channel Course Line - Vertically Up
  - Overlay of Ship Image and Land Image on Radar Display
  - Fading Line Showing Course History
  - Zoom Feature With Operator Variable Range
  - 2 Second Update Time
  - Color Preferred
- DATA READOUT
  - Course Line, Heading, Speed, Distance & Time to Next Waypoint, Course Line Next Reach, Minimum Distance to Channel Limit

FIGURE 18:DISPLAY REQUIREMENTS

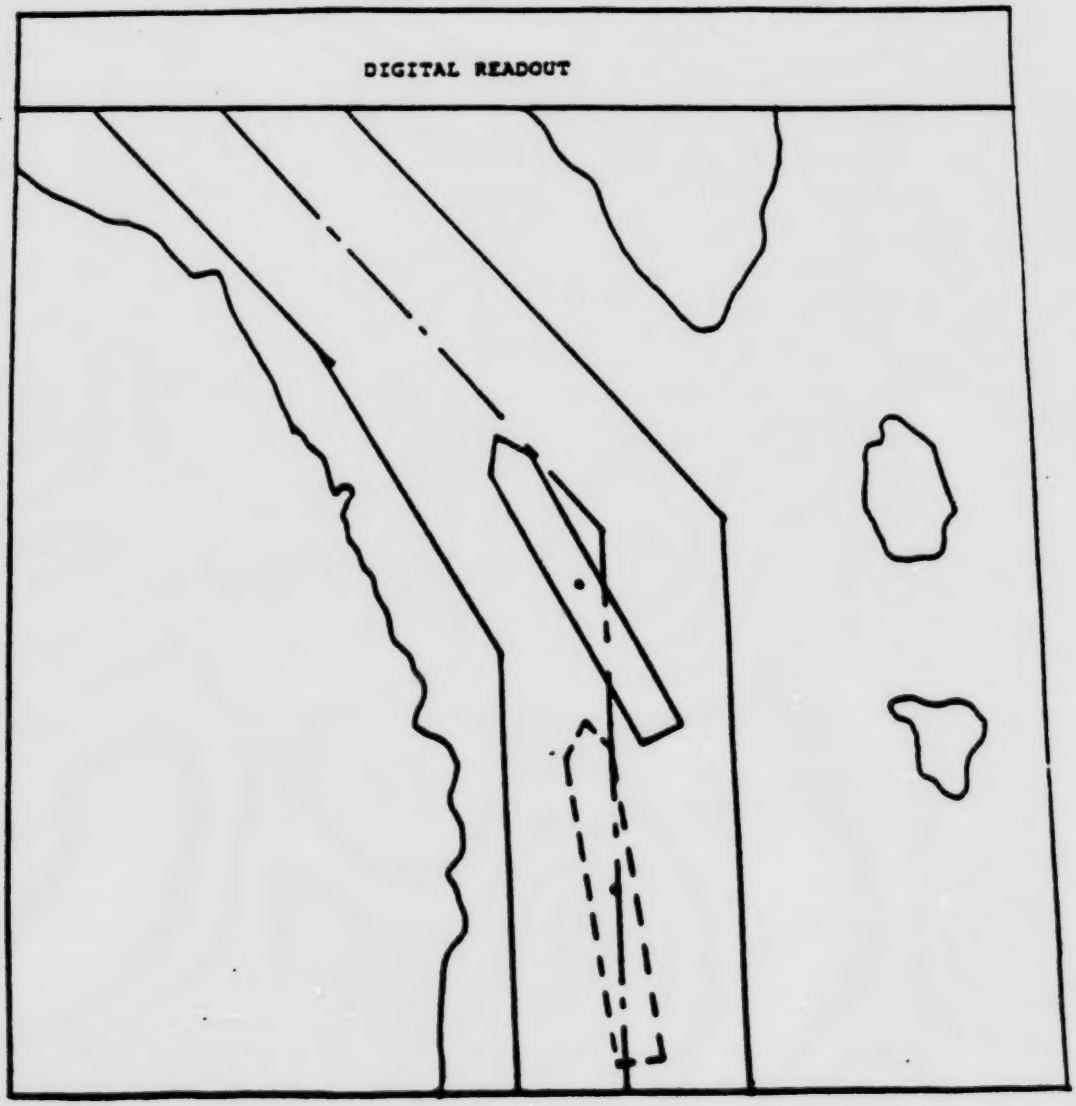
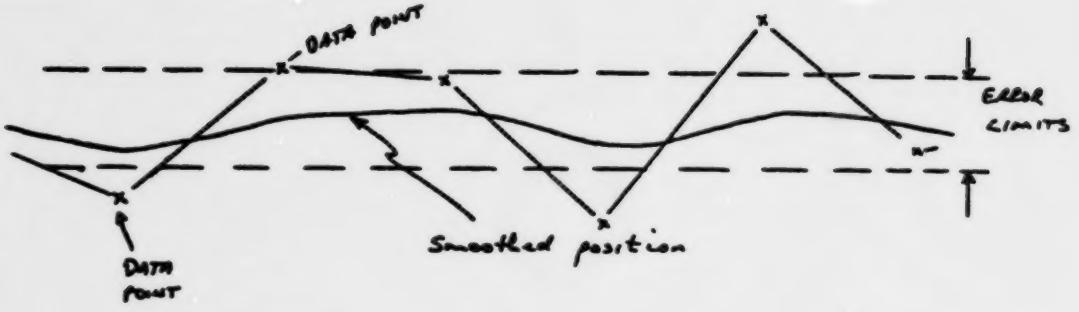


FIGURE 19:GRAPHIC DISPLAY



TRACKING

FIGURE 20:ERROR LIMITS AND TRACKING FILTER

seven points outside your limits.So in order to make sure that the operator is not guided by these data points as such the system would smooth the actual position by taking into account the previous position readings so that you would have a smoothing filter.This will improve the actual prediction of the system.By this way we can ensure that data points which are out of the way are not displayed to the operator.

The location techniques that we looked at included all these alternatives(fig 21)Of all the conventional positioning systems none could meet the accuracy requirements as a stand alone system so we only looked at them in the differential mode.Figure 22 shows the conventional marine systems available.Figure 23 shows some unconventional systems and figure24 shows the systems we selected as being acceptable and these we did a more detailed study on.Conventional maritime systems were found to have insufficient accuracy to meet the requirements.Differential Loran-C has been studied in the United States and although marginally accurate enough it was not considered reliable enough.Again MF phase comparison systems are marginally accurate enough but we felt that they too were not reliable enough because of the distances involved in the propagation and other such aspects.

Figure 24 shows the systems we found acceptable.I shall explain to you what they are.The first one, using radio transponders uses an interrogator on the ship and transponders on the shore.A processor on the ship takes the time of arrival of interrogated pulses from transponders at known shore locations and from these automatically computes the position of the ship(fig.25).These systems are fairly common and quite widely used.Figure 26 shows a typical layout of such a system installed on a reach of the Seaway.We looked at such layouts in order to get some idea of what the cost of installing it would be i.e. the number of transponders required.You can see that,in order to get good geometry to reduce geometric dilution of position,you have to be careful where you locate the transponders.As you get to a narrower part of the channel you need more transponders to ensure good geometry in those areas where your accuracy requirement becomes more critical in fog.

On this basis we analyzed the number of transponders required.This is quite a common form of analysis for any kind of transponder whether it be using a dedicated interrogator or the ships radar for interrogation.The next system we looked at was the radar transponder interrogated by the ships radar.The ships radar receives the returned and coded pulse and can identify the particular transponder.Figure 27 shows the radar processing system which extracts range and azimuth information from several transponders and feeds them to the tracking filter.The code detector identifies the particular transponder so the tracking filter can continuously use this information to update the position.All the information about the

LOCATION TECHNIQUES

ALTERNATIVES FOR CONSIDERATION

- Differential Omega
- Transit/Navsat
- Differential Loran
- MF Phase Comparison
- DF
- Laser System
- Sonar System
- DME-P
- Shore-Based Radar
- MLS
- Differential GPS
- Radio Ranging System (UHF or Microwave)
- Ship's Radar with Transponders
- Ship's Radar with Polarimetric Reflectors
- Ship's Radar Using Image Correlation

FIGURE 21:CANDIDATE SYSTEMS

*	Differential Omega	-Insufficient Accuracy
*	Transit/Navsat	-Insufficient Accuracy
*	DF	-Insufficient Accuracy
*	Differential Loran	-Questionable Accuracy and Reliability
*	MF Phase Comparison	-Marginally Usable not Sufficiently Reliable

FIGURE 22:CONVENTIONAL MARITIME SYSTEMS

*	Laser system	-Not All Weather
*	Sonar system	-Susceptible to Ice Scour
*	DME-P	-Insufficient Accuracy
*	Shore Based Radar	-Complex and Unreliable
*	MLS	-Complex and Unreliable

FIGURE 23:NON-ACCEPTABLE SYSTEMS

* Radio Ranging System (UHF or Microwave)
* Ship's Radar with Transponders
* Ship's Radar with Polarimetric Reflectors
* Differential GPS
* Ship's Radar Using Image Correlation

FIGURE 24:ACCEPTABLE SYSTEMS

CAL

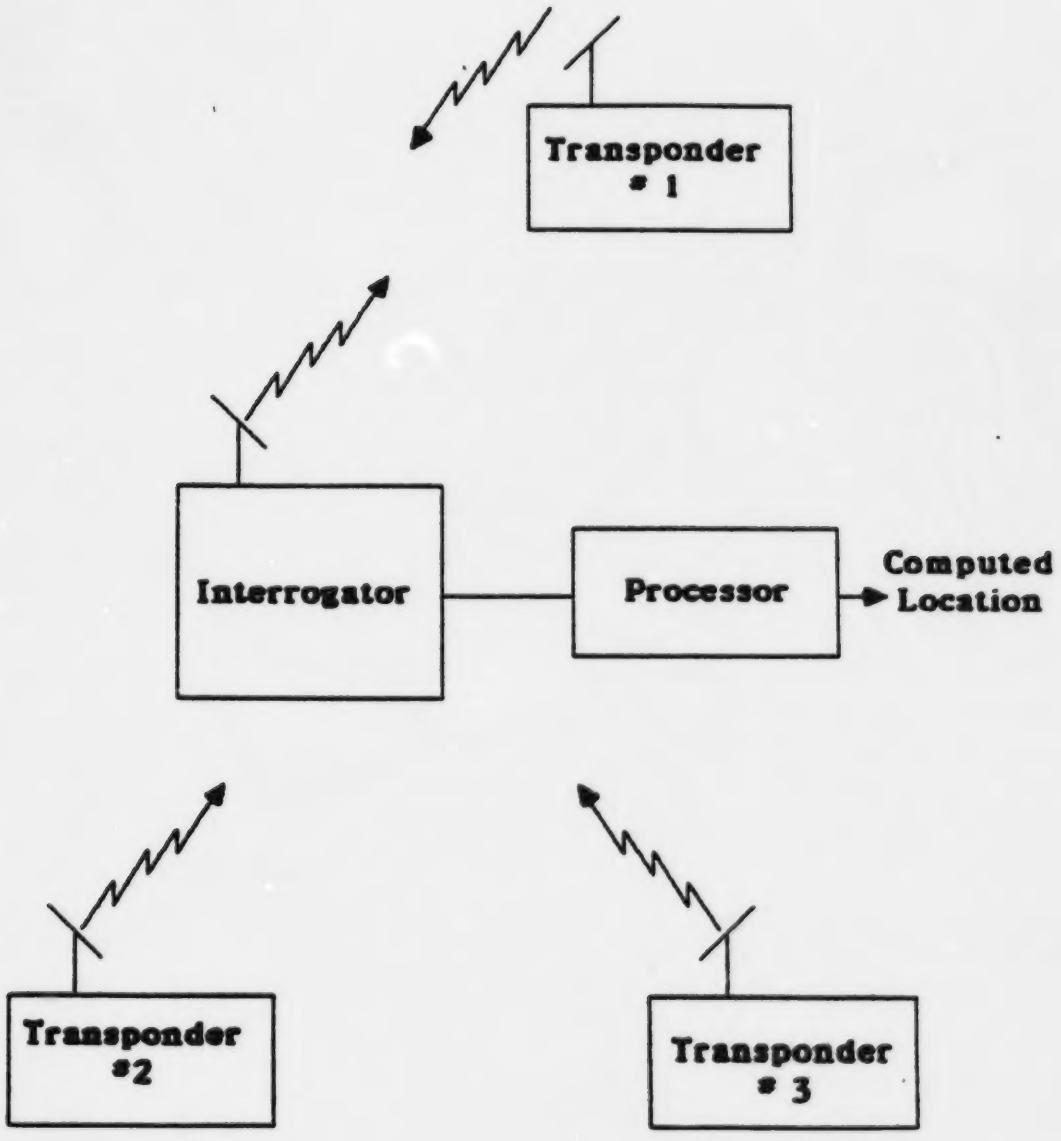


FIGURE 25:MICROWAVE TRANSPONDER SYSTEM

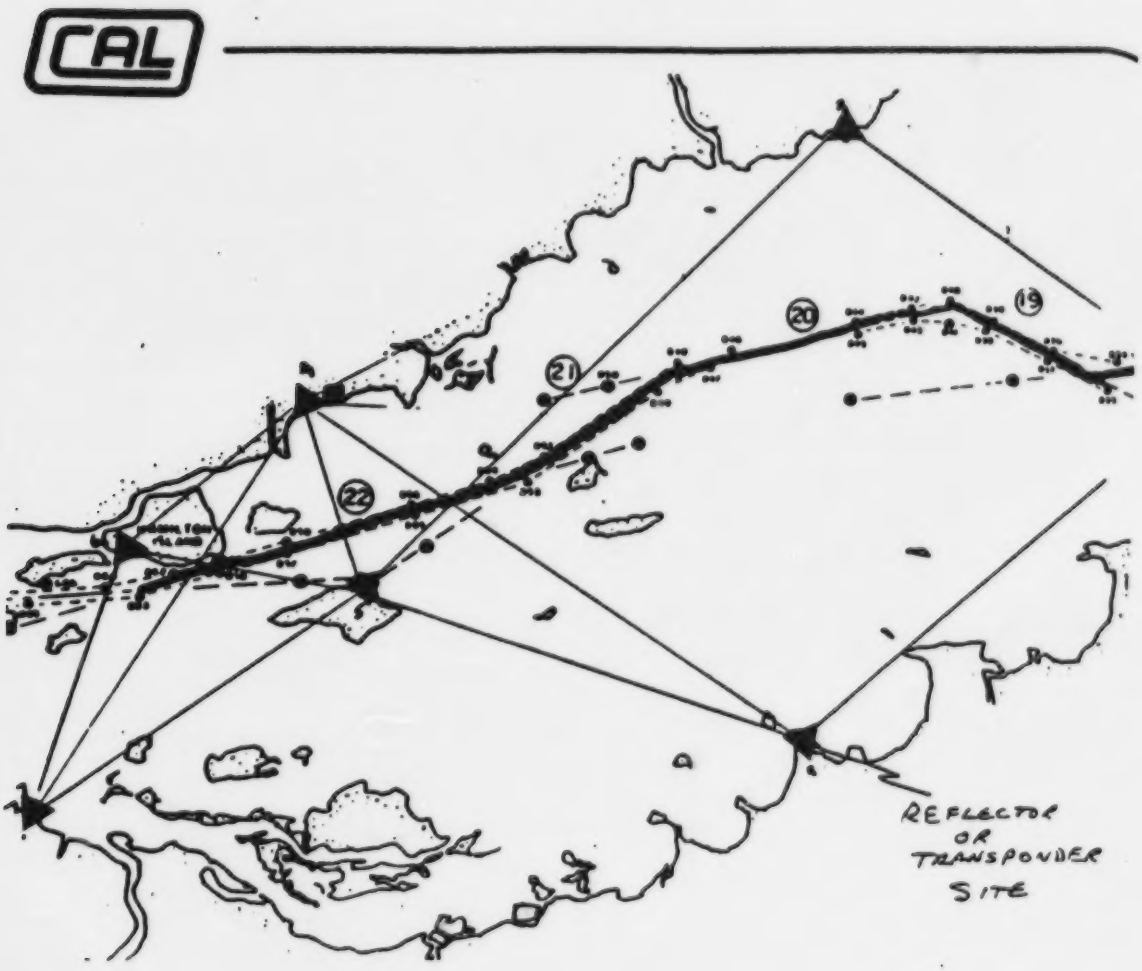


FIGURE 26: TRANSPONDER SYSTEM LAYOUT

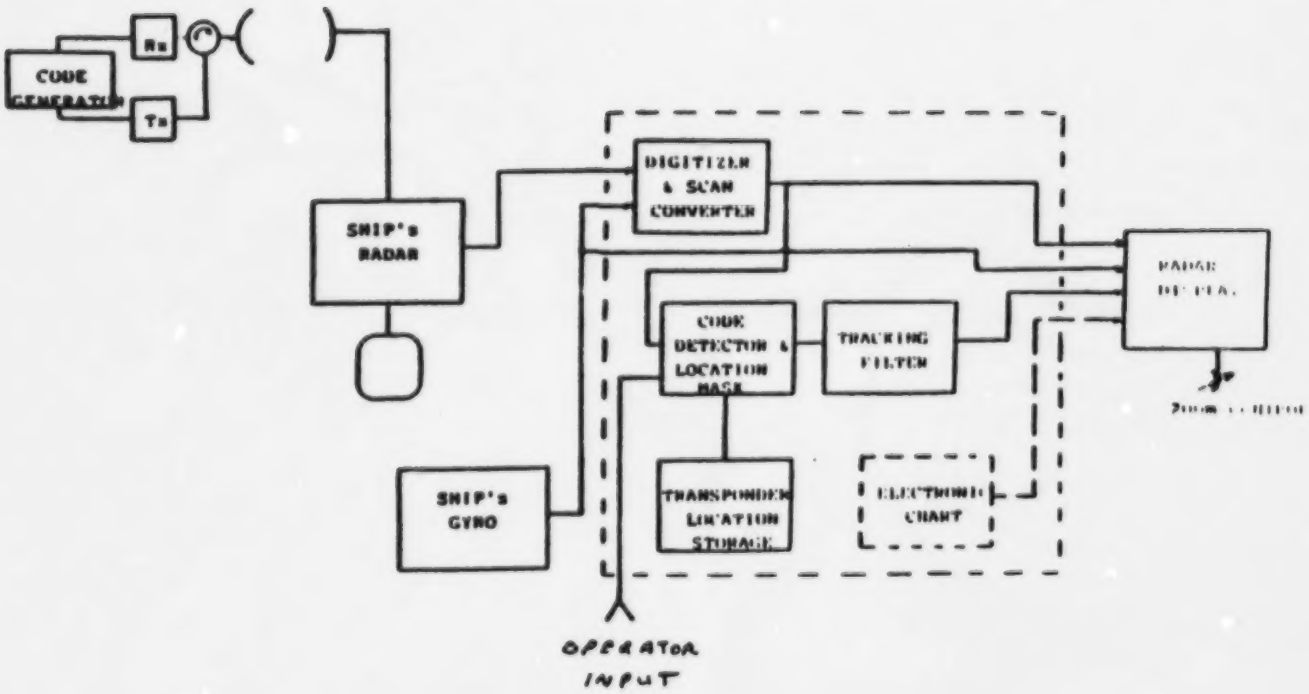


FIGURE 27:RADAR TRANSPONDER SYSTEM BLOCK DIAGRAM

transponders and their code and location is stored in memory.In addition the electronic chart information can be stored here also and the radar information can be superimposed on the electronic chart.

The second system(fig.28) using the ships radar is a polarimetric reflector system.What we do is send out a horizontally polarized radar pulse to a passive reflector on the shore which changes the polarization from horizontal to vertical and reflects a vertically polarized pulse back. This pulse is received by a different antenna on the ships radar. The vertically polarized receiver will discriminate strongly against horizontally polarized clutter.Thus only the vertically polarized signal from the reflector will appear at the output of the receiver.As before we use the gyro output and the receiver output ,which can be digitized,to compute the ships position, which in turn can be superimposed on the electronic chart.

The image correlation system(fig. 29) uses a radar map stored in memory.As the ship passes along the channel the radar image is compared to the stored image by digitizing it and performing a mathematical correlation with the stored image.By doing this correlation and by getting that position which gives the perfect match you can work backwards to find your position and as before we can integrate the electronic chart information.To do image correlation the system needs a reasonably accurate initial position which could be supplied by Loran or other such system.All these systems are compatible to inputs from several sensors such as GPS,Loran etc.

The next system we looked at was differential GPS where you have a GPS receiver and another "differential station"which measures the GPS signal at an accurately surveyed site;determines the GPS error and transmits it to the ship.This is received over a data link and sent to a differential processor which feeds the tracking filter.Figure 30 addresses this linkage.

In all these systems what you will get is the image which will come out on a TV display which can come out in color (fig.31) which will indicate all of this information.The position of the ship with respect to the channel coastline,the angle at which the ship is tilted, the clearance between the front and the back of the ship (which will be indicated on the digital readout)the position (again on the digital readout)the distance to next way point and the speed (which can be calculated very accurately by the tracking filter will all be displayed.

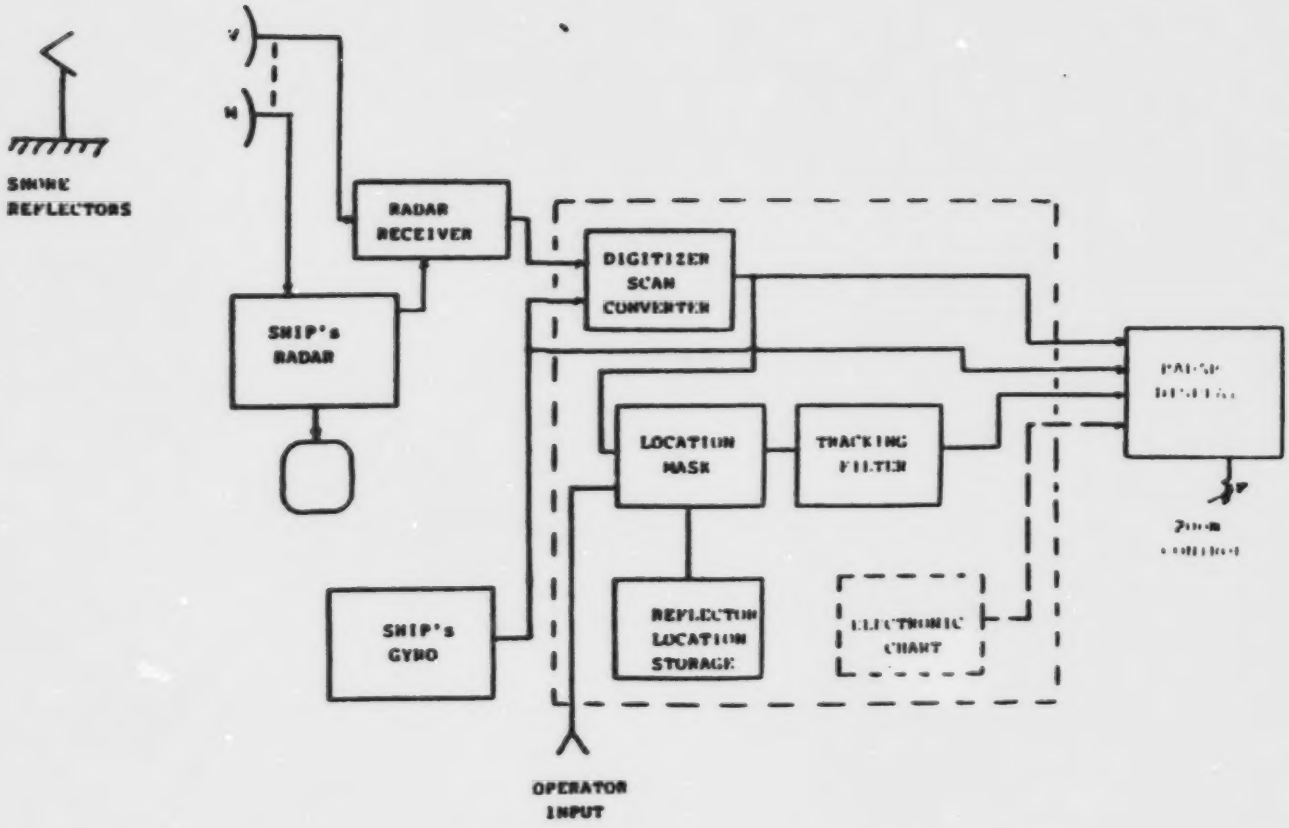


FIGURE 28:POLARIMETRIC RADAR BLOCK DIAGRAM

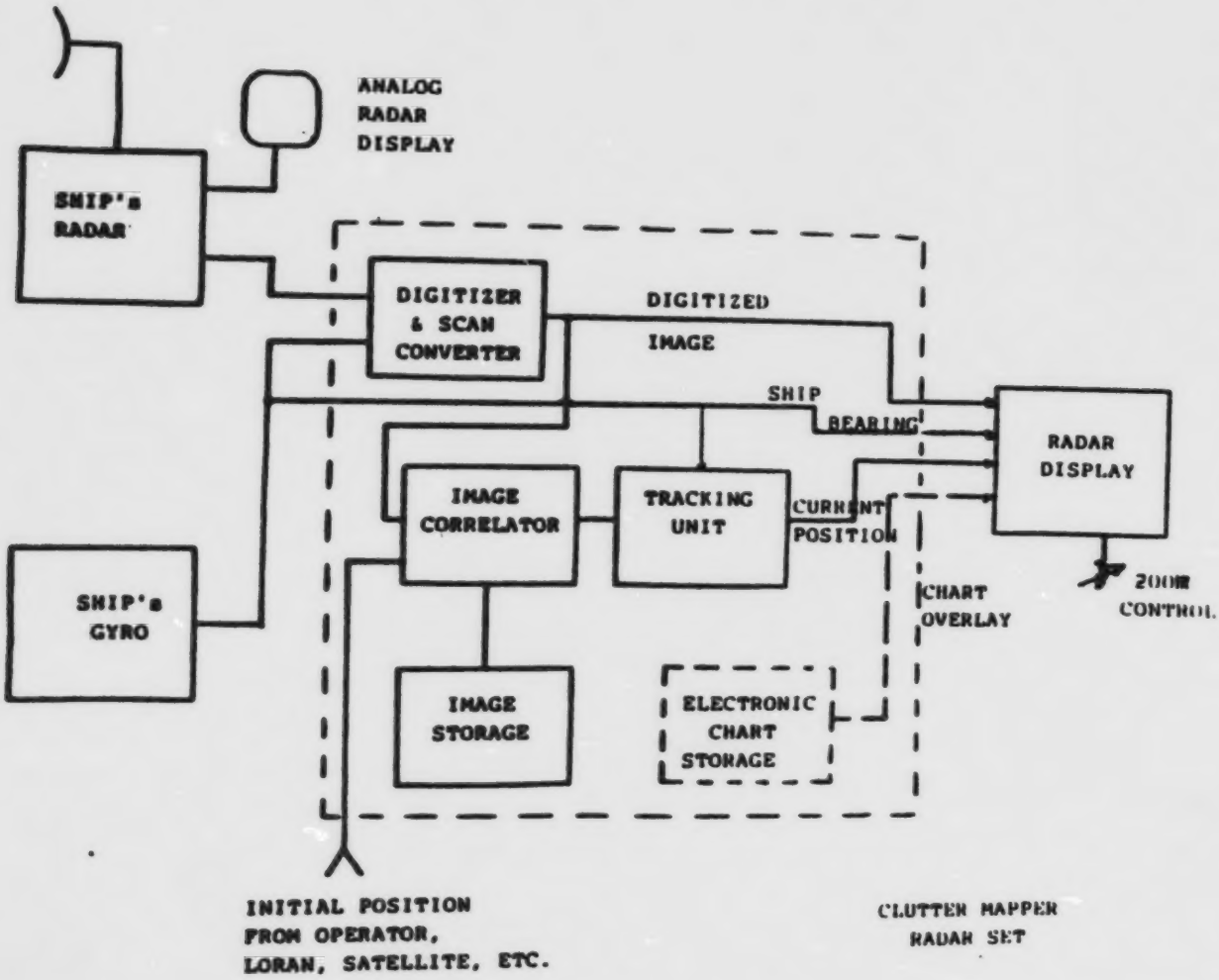


FIGURE 29: IMAGE CORRELATION RADAR

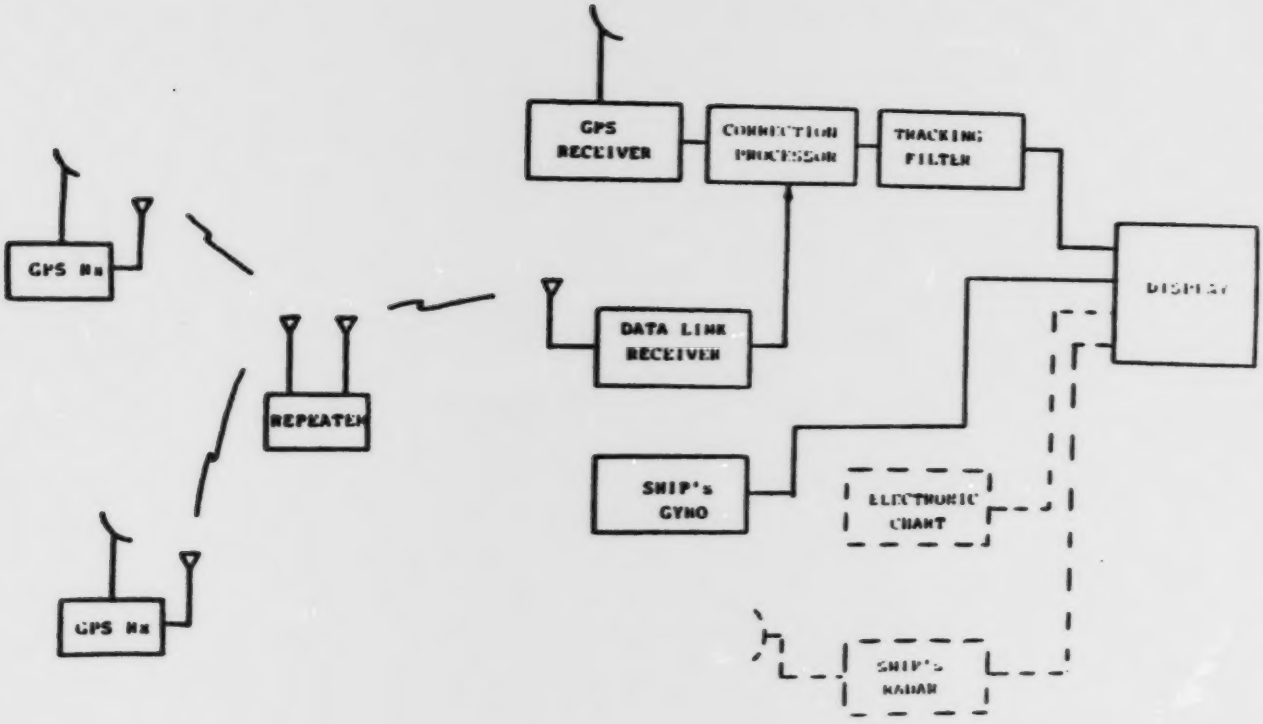


FIGURE 30:DIFFERENTIAL GPS SYSTEM BLOCK DIAGRAM

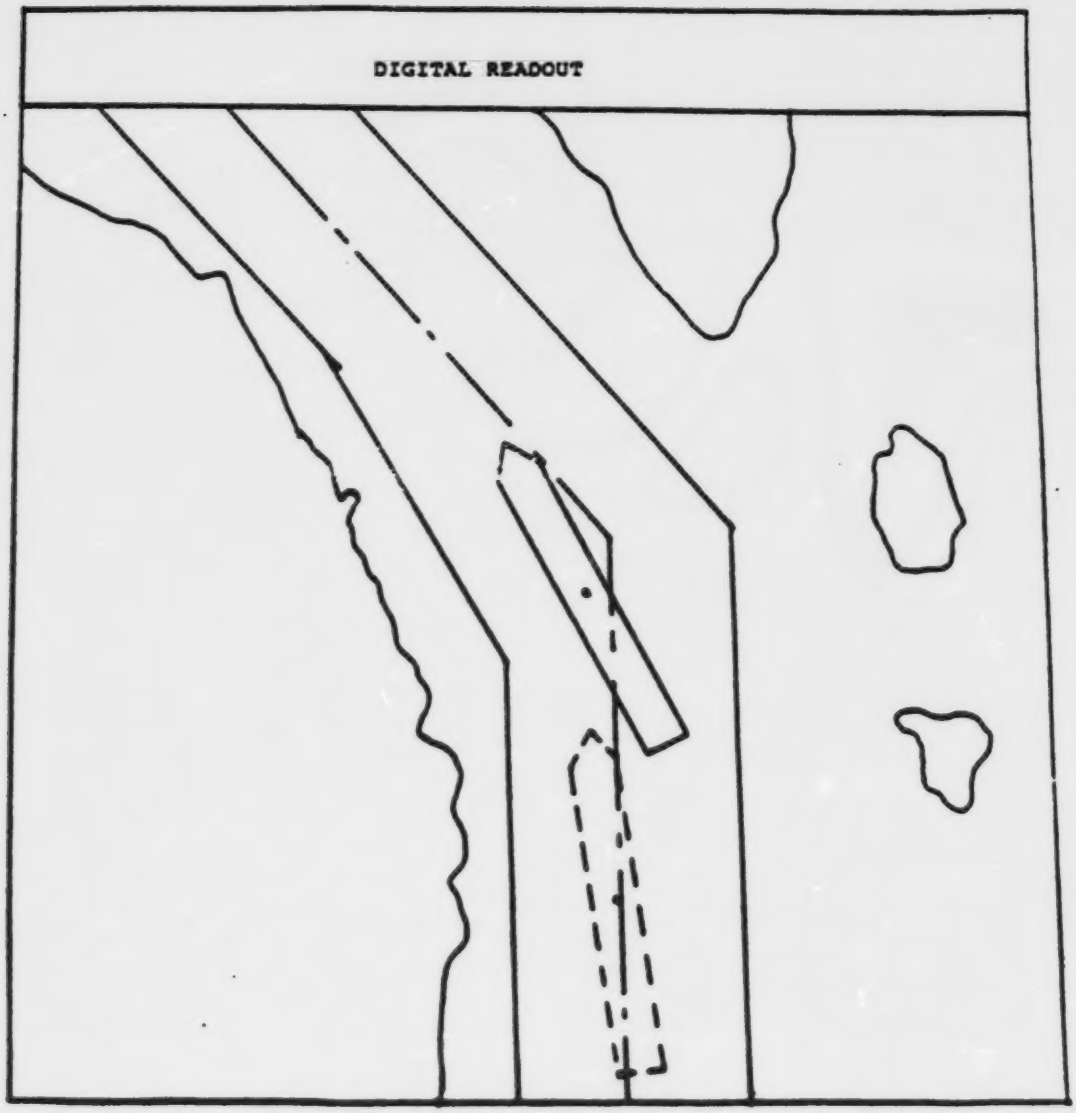


FIGURE 31:CONCEPTUAL SYSTEM TV DISPLAY

I should like to talk a little about the tracking(fig.32).The advantage of using tracking is that you have a continuous update on the position of the ship.It also helps in smoothing the position data.Tracking can also be done on the heading data so if there is any interruption of the system either the positioning system or the gyro the problem can easily be located.The ships motion is of course continuous between updates so it is very easy to incorporate tracking.Tracking can be used to estimate the future position of the ship.Tracking can be used as a consistency check on the position and heading data.While there are many methods of optimally filtering the data we looked at the alpha-beta tracker and the Kalman filter.

Figure 33 shows the block diagram of the tracking operation. First you have the target detection then we have a track association with the target then you have a trilateration done.For example if you have a system of transponders you have an inverse trilateration on three positions then afterwards you can do the position tracking then you can do a prediction to estimate the future position then you can go back to the target detection.This means that the system already has a knowledge of future positions so that it can do a highly localized search and detection rather than a global search.

Figure 34 shows system operational requirements.All these systems require use of the ships radar and in turn this creates a need for calibration of the system and ships radar periodically to ensure that there are no problems with jitter or frequency change. Resolution which is not normally attainable on the ships radar is obtained here by digitizing the image.What we are doing is changing the radar signals into a format which is easily processed and displayed on a TV like format. The display could for example be 512 by 512 pixels which is a very high resolution display;a much higher resolution than a standard PPI.

Figure 35 shows the choice of systems. Systems 1&2 were felt to be too expensive due to installation,maintenance and power costs.Systems 3,4,&5 will be discussed later this afternoon by Dan Ball.

TRACKING

- Ship's Motion Is Continuous Between Updates Due To Ship's Dynamics
- Tracking Used To Smooth Position Data
- Tracking Used to Predict Future Position
- Tracking Used To Check Consistency of Position and Heading Data
- Tracking Algorithm
    - Alpha-Beta Tracker
    - Kalman Filter

FIGURE 32: TRACKING FILTER

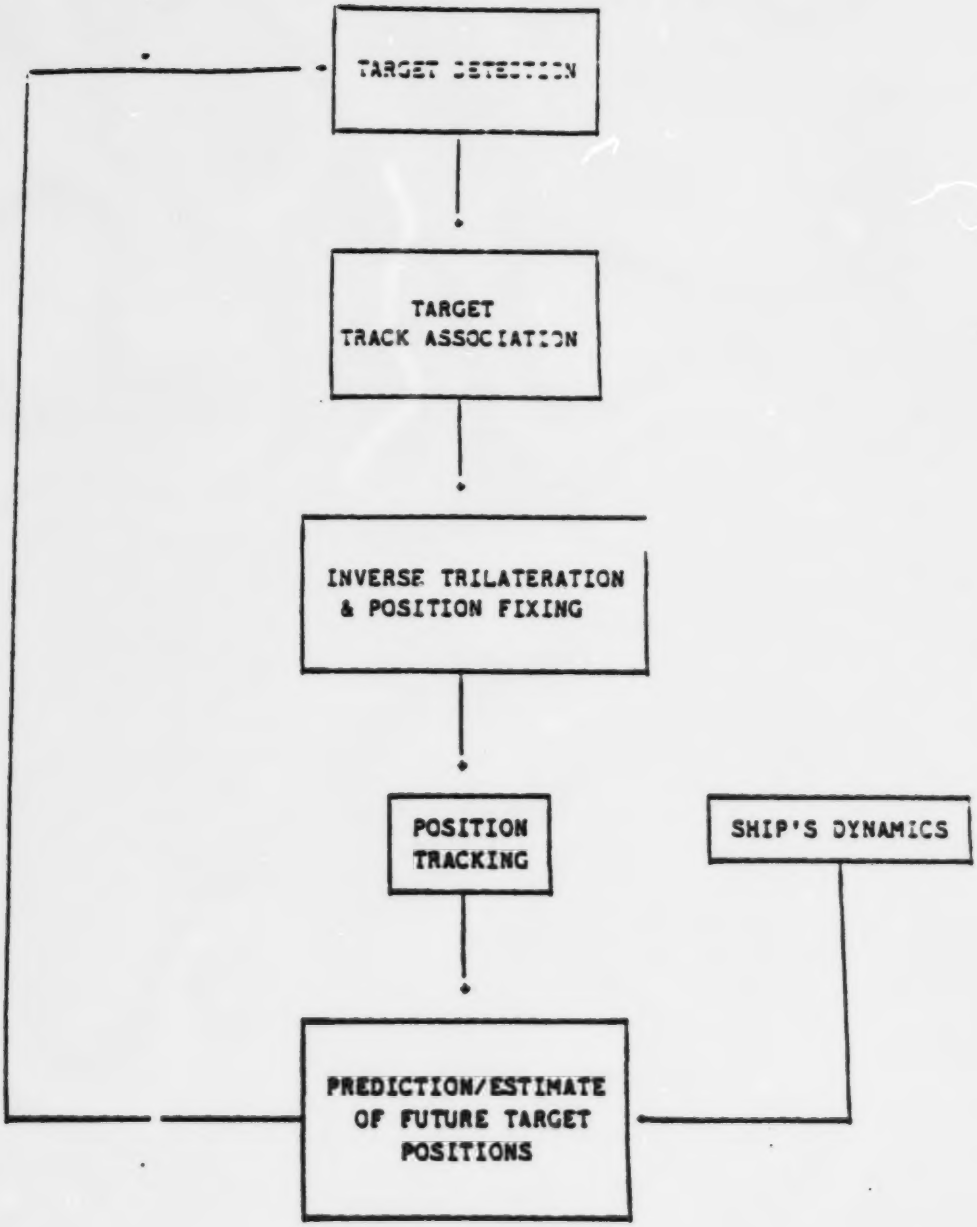


FIGURE 33:TRACKING ALGORITHM

* Sufficiently Accurate
* Technology Proven or Well Known
* Reasonable Cost
* Compatible With Existing Ship's Radar
* Compatible With Marine Navaids (Loran,GPS,Etc.)
* Compatible With Electronic Chart
* Adequate Failure Response Time
* Adequate Health Status Check
* Easily Usable By Ships Captain

FIGURE 34:SYSTEM REQUIREMENTS

1 Radio Ranging System (UHF or Microwave)
2 Ship's Radar With Transponders
3 Ship's Radar With Polarimetric Reflectors
4 Differential GPS
5 Ship's Radar Using Image Correlation

* Systems 1 & 2 Too expensive
  - Require Powered Shore Based Units
    Installation
    Maintenance
    Power Source

FIGURE 35:TECHNICALLY ACCEPTABLE SYSTEMS

Mr. Bertrand called for comments from the floor.

Question: Mr. M.Walker:Transport Canada.

Both Mr. Raman and Mr. Luce have shown great interest in differential GPS. What type of implementation do you propose for this? Are you proposing a code independent implementation or are you proposing simply a surveyed receiver that decodes the GPS signal finds a differential correction and then merely transmits the correction?

Reply: Mr.Raman:

We looked at three or four GPS implementations.One of them could just be transmitting the location of the differential station and the code.The second could be relaying the code as such directly to the ship.There are two or more other systems we looked at.We still are not too sure about the capabilities,accuracies and advantages in each of these cases since they are still being studied.No conclusive reports have appeared comparing all these systems.

Comment: Mr.Walker:

I have no question about the accuracies, that I feel is a given.The problem is,if you are dependent on access to the GPS codes then these could be shut off and alternatively if you go to a code independent system then you are putting yourself into the position where you need a very wide bandwidth signal and can you in fact get a spectrum allocation from DOC that will allow you to transmit that high a bandwidth signal?

Reply : Mr.Raman:

In fact you can still do it with the P code and that can give you reasonable accuracy.

Comment:Unknown Speaker:

I think the question really was,did you investigate codeless systems?

Reply: Mr.Raman:

We didn't investigate in detail. What we looked at were three or four systems but we couldn't come out with a study that would compare all systems.I don't know what sort of performance you could have with different systems.

POLARIZED RETRO-REFLECTORS

Results of recent work:Dr. S.Haykin,Communications Research Laboratory McMaster University

Our involvement with this particular type of radar goes back about five years ago when we were first approached by the TDC to look into how one can indeed,through the use of passive reflectors,provide the solution to the precise navigation problem.I am going to present to you first of all a general outline of what our system consists of and then I will follow that up with a fifteen minute film showing the system in operation.

We call our system Polarimetric Radar for Accurate Navigation PRAN(fig.36).I guess we always have to come up with a new name for a system,well this is ours.Figure 37 shows the present project staff associated with this effort.I have to say that I have just come back from a brief trip to the west coast of the United States having had the pleasure of visiting JPL. Needless to say if this kind of effort were being carried out right there right now what you see in figure 37 would have been multiplied a good four or five times.

As you can see from the slide(fig.38) the talk will consist of:what the precise navigation problem is;the radar discriminants that one can look at to solve the problem;the solution that we have come up with to solve the problem;the passive polarimetric reflector that we have invented;a description of the experimental setup;experimental results and the current status of our research.

Figure 39 gives you an overview or conceptualization of the system.We have a series of reflectors that are positioned along the shoreline and in effect,the ships radar communicates with them.If one were to examine all the possible radar discriminants that there are; that,(fig.40) would be the list. There really is no other items that I can add to the list.

Well if I were to look at each one of them and examine them in the context of the problem at hand without any bias (which is what we did) one would have to exclude amplitude,simply because there is no way you could pick a reflector big enough for you to communicate with in a reliable sort of a fashion.So amplitude is out.Frequency and phase likewise are dead.Range?well it doesn't quite apply to the present situation neither does angular position.Doppler? obviously if the reflectors are going to fixed in position there is no Doppler shift to be responded to.So that is out.Shape? is not quite appropriate to the problem and that leaves polarization as the only solution.

The technical requirements that we had to face in building our system were the following(fig.41).First it had to be passive.Indeed that was a requirement that was passed

P olarimetric
R adar for
A ccurate
N avigation

FIGURE 36

Communications Research Laboratory
McMaster University

Faculty : S. Haykin

Research Staff : R. Cho
B. Currie
T. Greenlay

Graduate Students : E. Lee
A. Macikunas
A. Ukrainec

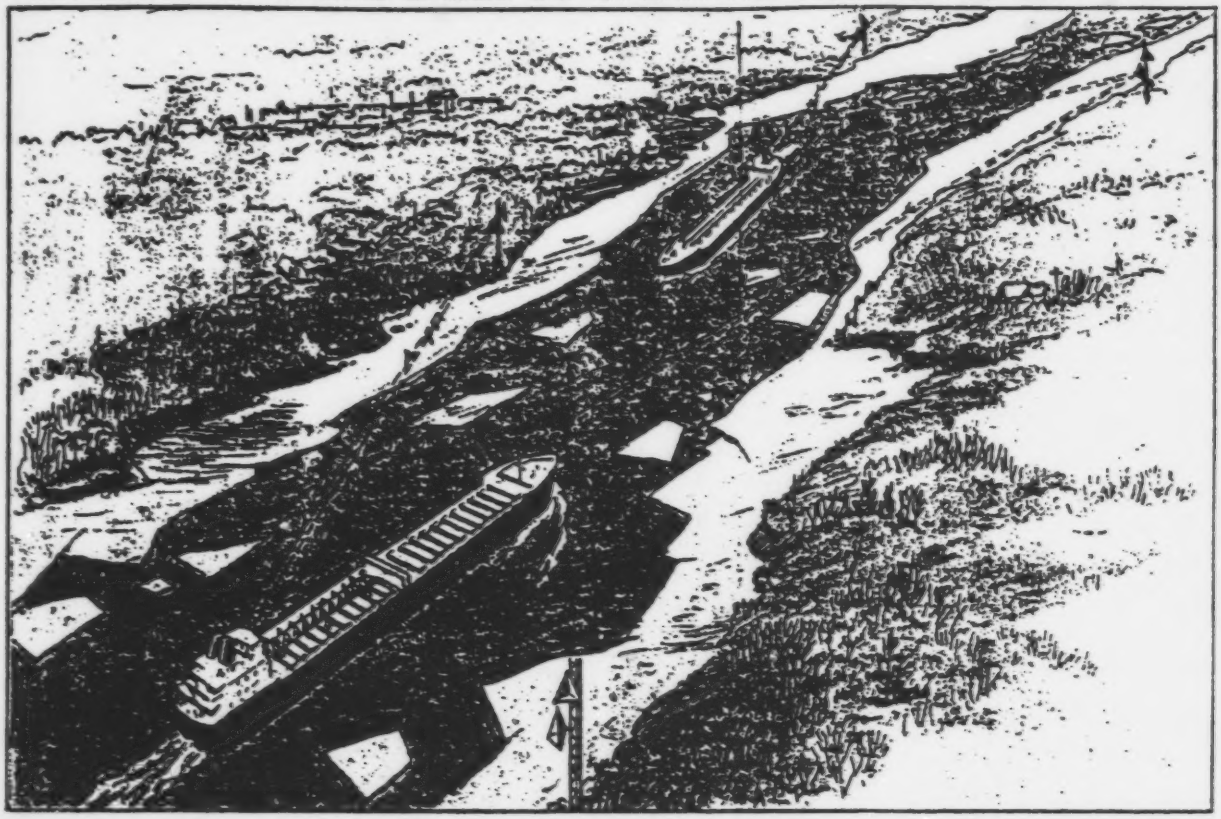
FIGURE 37:PROJECT STAFF

OVERVIEW

1. THE PRECISE NAVIGATION PROBLEM
2. RADAR DISCRIMINANTS
3. THE SOLUTION TO THE PROBLEM
4. THE PASSIVE POLARIMETRIC REFLECTOR
5. EXPERIMENTAL SET-UP
6. EXPERIMENTAL RESULTS
7. THE CURRENT PHASE OF RESEARCH

FIGURE 38:PRAN TASK OVERVIEW

A RADAR WITH SHORE-BASED CO-OPERATIVE PASSIVE REFLECTORS



FRCM DOMINION MARINE ASSOCIATION REPORT TP 2800 (1981)

THE SOLUTION —

A RADAR WITH SHORE-BASED CO-OPERATIVE PASSIVE REFLECTORS

FROM DOMINION MARINE ASSOCIATION REPORT TP 2800 (1981)

FIGURE 39:SYSTEM CONCEPTUALIZTION

AVAILABLE RADAR DISCRIMINANTS

- AMPLITUDE
- FREQUENCY / PHASE
- RANGE
- ANGULAR POSITION
- RELATIVE VELOCITY (DOPPLER)
- SHAPE
- POLARIZATION

FIGURE 40: RADAR DISCRIMINANTS

POLARIMETRIC RETRO—REFLECTOR TECHNICAL REQUIREMENTS

- PASSIVE OPERATION
- WIDE ANGULAR RESPONSE
- HIGH CROSS—POLARIZED RCS
- HIGH EFFICIENCY
- LOW COST
- RUGGEDNESS

FIGURE 41: TECHNICAL REQUIREMENTS

on to us by TDC.It had to have a wide angular response because clearly, the ship moves along and you want to see that reflector as you go along.It has to have a high cross polarized radar cross section,in order to provide precise discrimination.It has to be efficient.It has to be low cost.It has to be rugged.

Figure 42 shows our solution and indeed that solution has been patented.The patent has been granted in Canada and we are currently waiting for the result of our application in the United States.Basically it is really quite simple in fact if one thinks about it,it is really quite ingenious.You have a trihedral reflector with a wire grid twister that you position on one of the inside faces of reflector.The net result is that you change the polarization of the incident wave through 90 degrees.Not only that but you are able to do that change over a very wide range of values.

Here indeed(fig.43) is the response of the reflector as measured in the laboratory.A point was made earlier on,by Mr. Raman that one had to somehow calibrate the radar with regard to possible frequency changes.Here you can see the frequency in this particular case changing all the way from 8 to about 11GHz.You will notice that there is hardly any change in the response of the reflector.The couple of traces you see across the top are what you measure with the cross polarized return with wire twister in place.What you see in the lower trace is the result of using the reflector without that twister.

Figure 44 shows the antenna presently being used,it's an Andrew antenna.It is a single antenna that is dual polarized with a rotary joint.Figure 45 shows the equipment itself. It is built around a Decca marine radar.

Figure 46 shows the results of measurements made on the system.That's what you have in response to a reflector located at Dofasco.We chose the Dofasco site because of its rather hostile nature to radar signals.That's what you would measure on a normal radar display.That indeed is the result of displaying what you would measure on the horizontal polarization(upper) and what you would measure on the vertically polarized antenna(lower) but without the reflector in position.Clearly there is a little bit of leakage and that is largely the result of the poorly matched antenna design that we are presently using.

Figure 47 shows the same thing again but this time around you see the reflection due to the passive reflector popping out quite nicely.Figure 48 shows similar results of the case of the reflector located at La Salle park which is somewhat less hostile.Again the lower trace is what you would measure without a reflector.The upper trace is what you would measure on a normal display.Figure 49 shows what you would get with the reflector in position and it pops out quite nicely again.

A TOWER-MOUNTED TRIHEDRAL TWIST-GRID RETRO-REFLECTOR

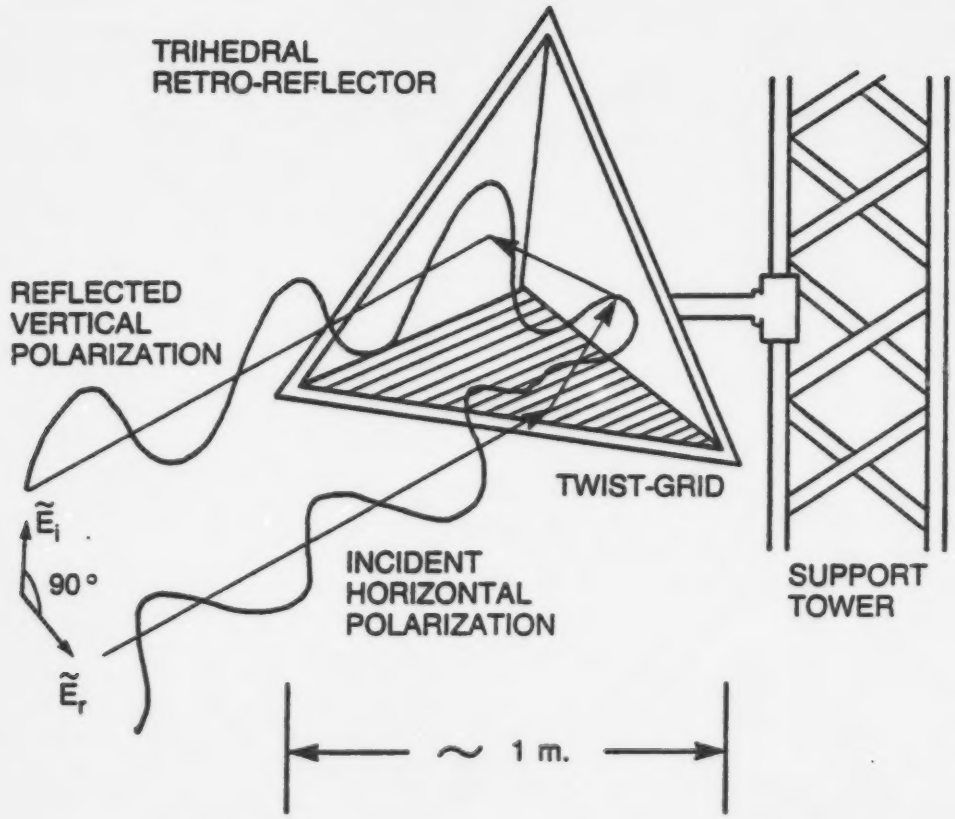


FIGURE 42: THE McMASTER SOLUTION

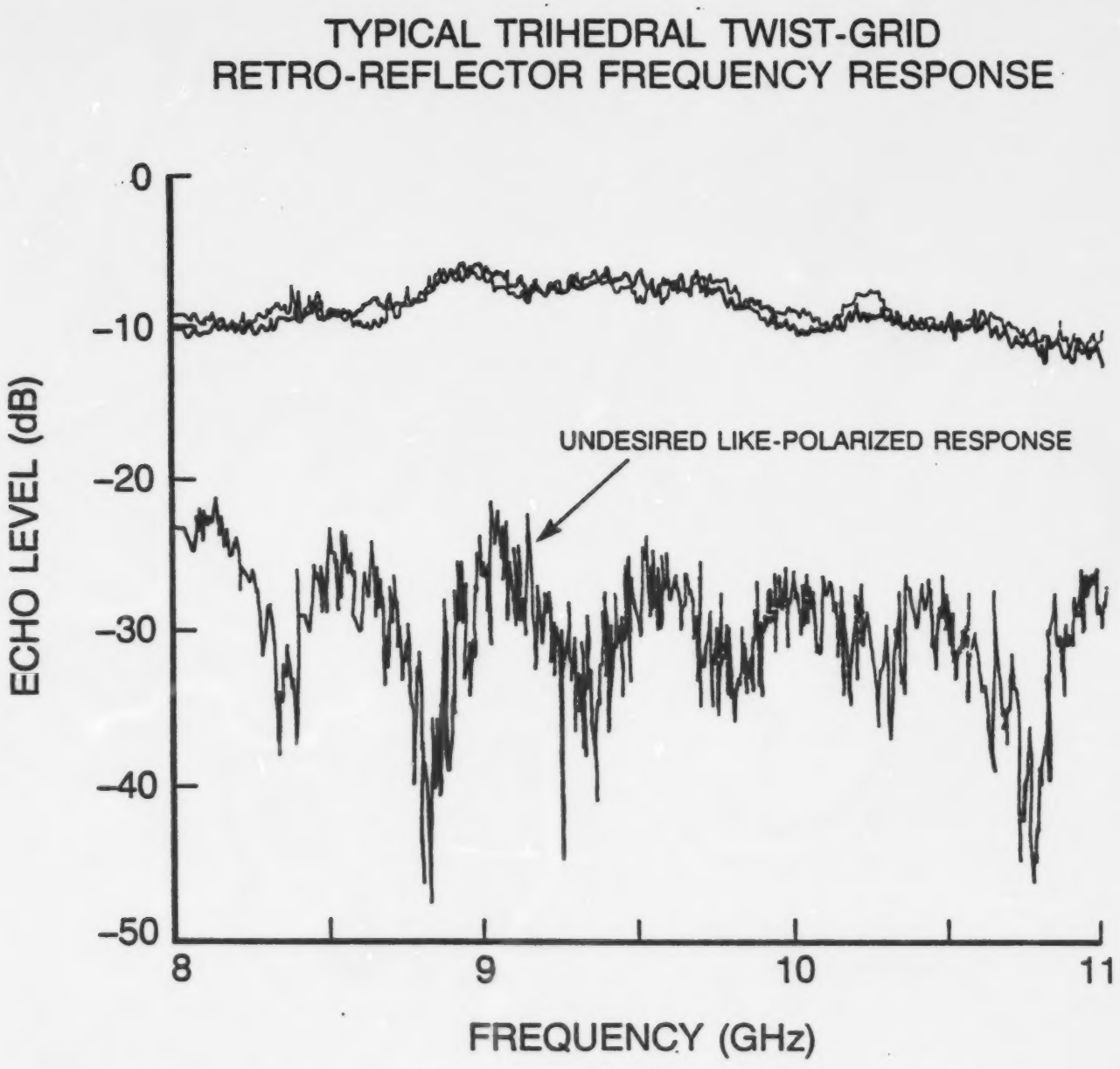
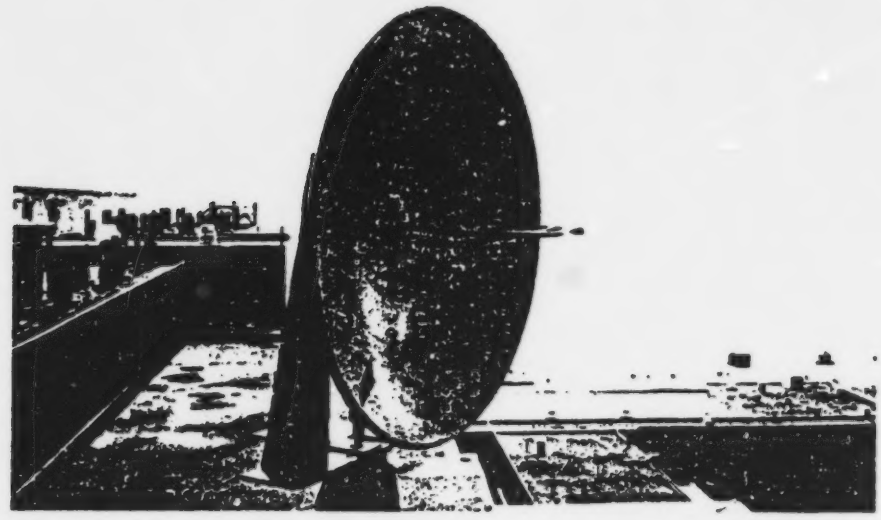
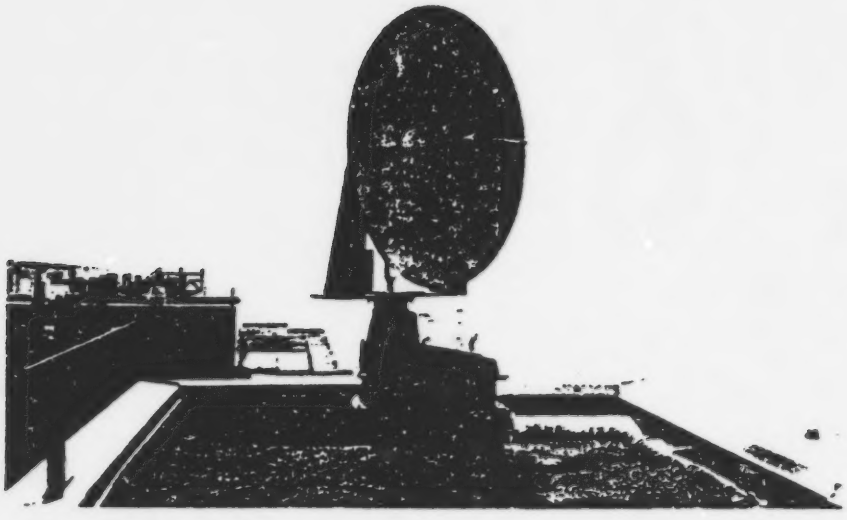


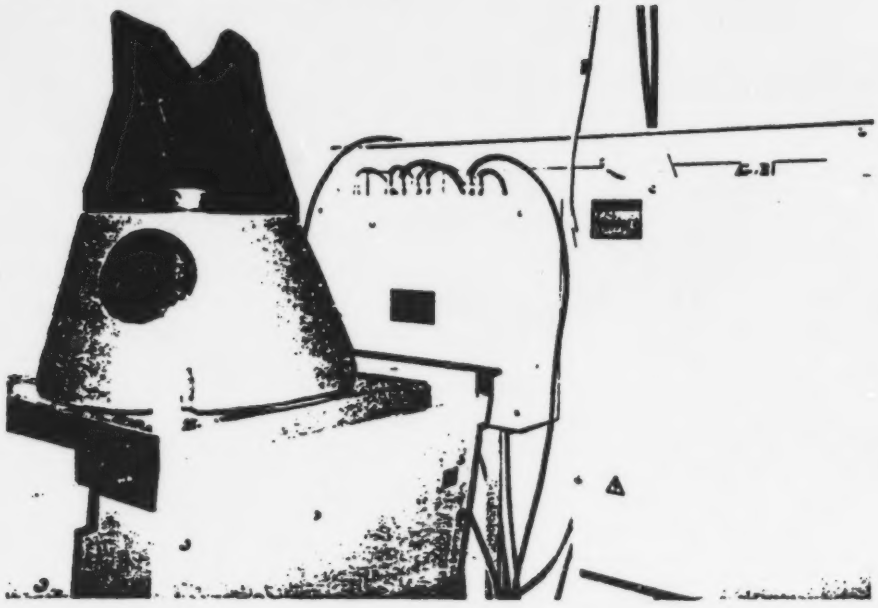
FIGURE 43:POLARIMETRIC REFLECTOR RESPONSE



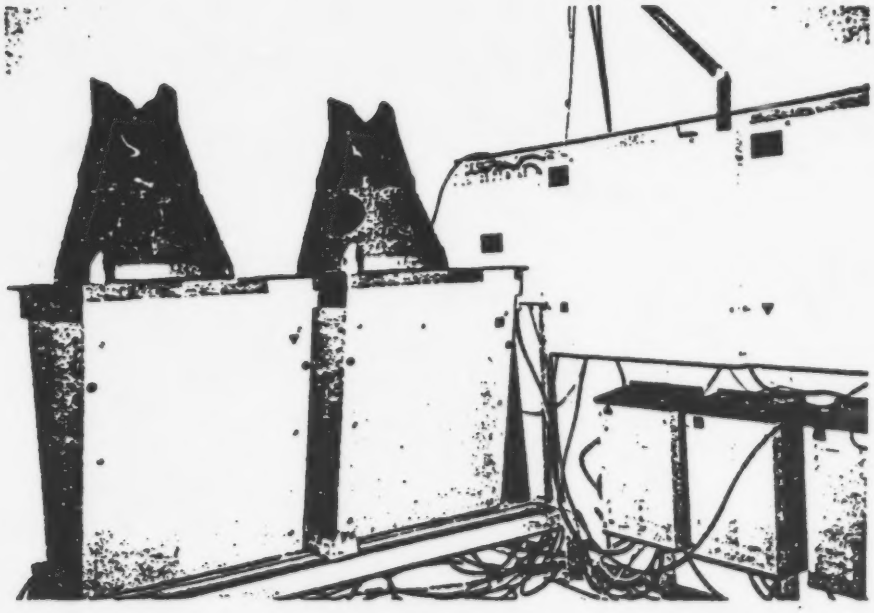


Parabolic Antenna Dish with
Dual, Linear Polarized Feed

FIGURE 44:POLARIMETRIC RADAR ANTENNA

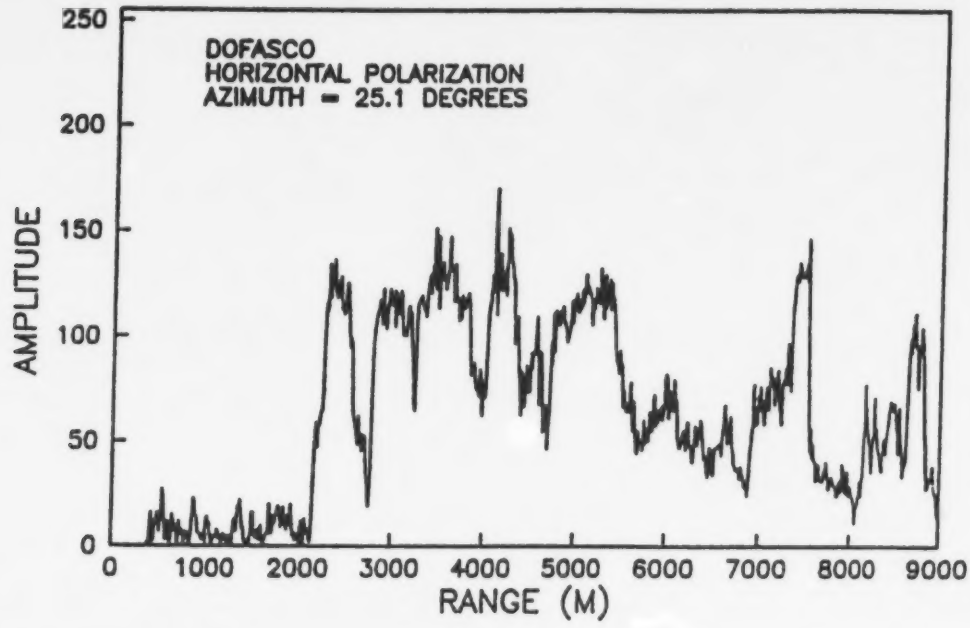


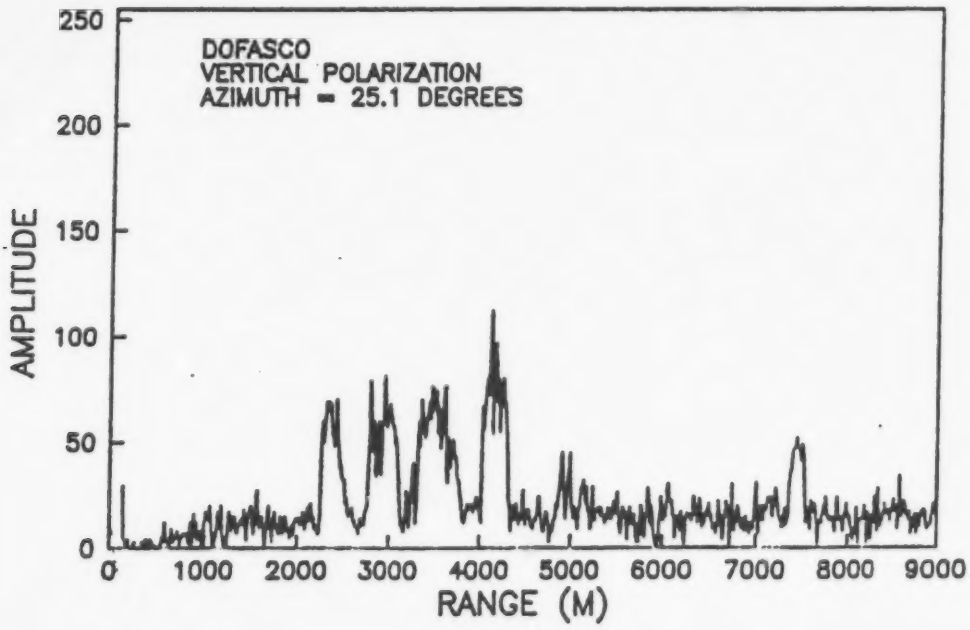
L-R: PPI Display, Sector Blanking Unit, Transceiver



Radar Components: PPI Displays, Sector Blanking Unit, Transceivers and Rectifiers

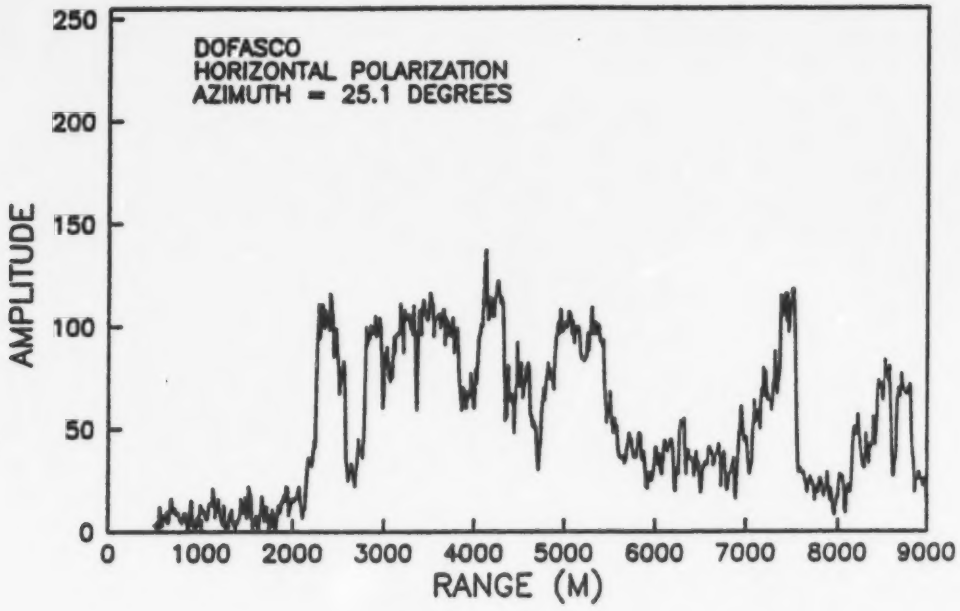
FIGURE 45: POLARIMETRIC RADAR EQUIPMENT

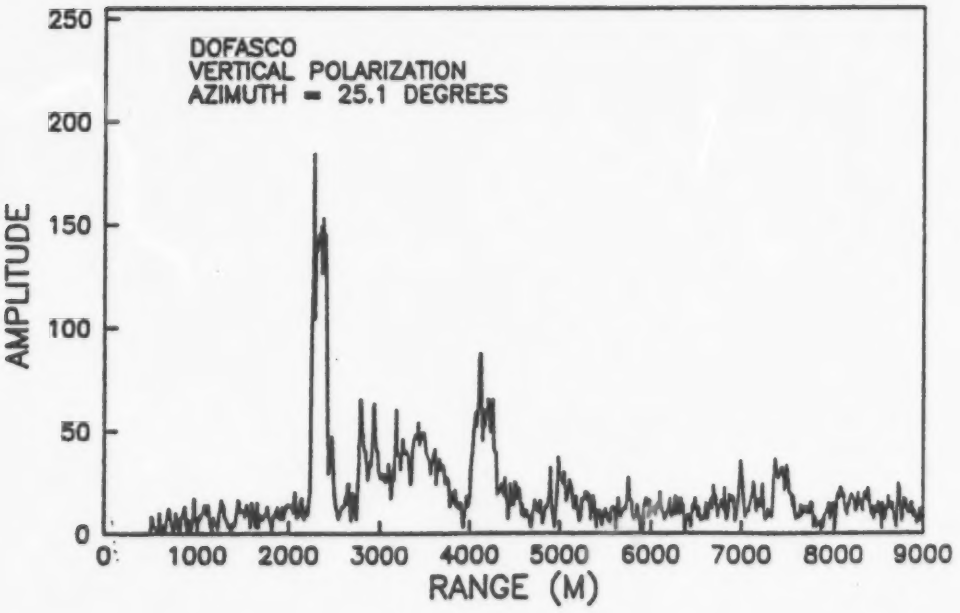




Horizontally and Vertically Polarized
Sweeps of the Dofasco Site
(No Reflector)

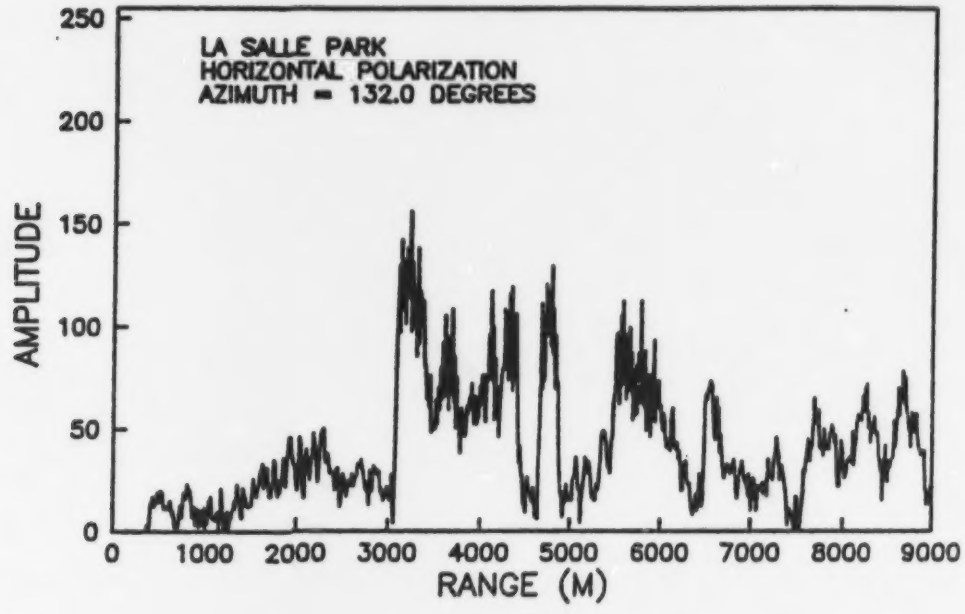
FIGURE 46:RESULTS;DOFASCO SITE

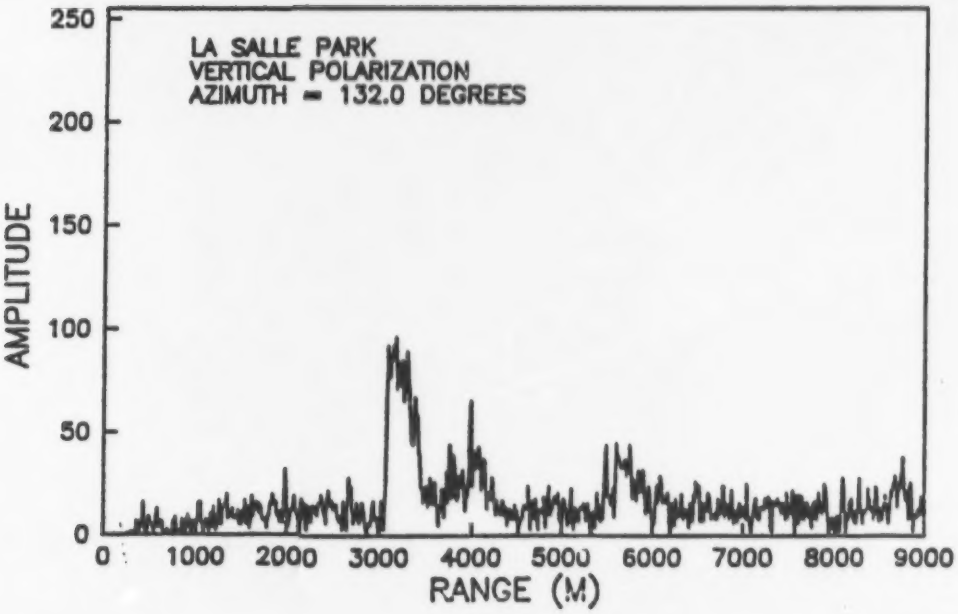




Horizontally and Vertically Polarized
Sweeps of the Dofasco Reflector

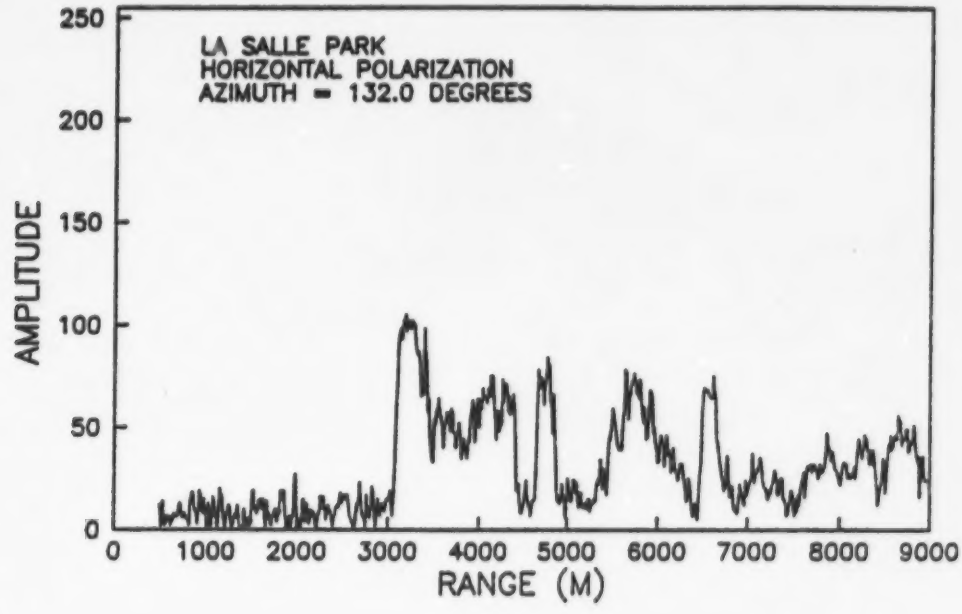
FIGURE 47:REFLECTOR RESULTS;DOFASCO SITE

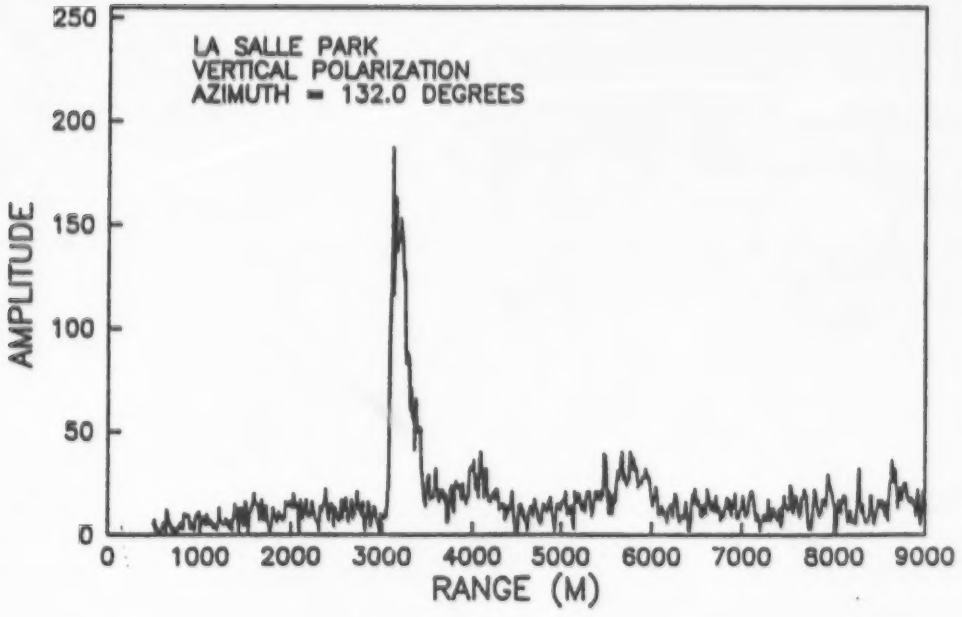




Horizontally and Vertically Polarized
Sweeps of the La Salle Park Site
(No Reflector)

FIGURE 48:RESULTS;LA SALLE PARK SITE





Horizontally and Vertically Polarized
Sweeps of the La Salle Park Reflector

FIGURE 49:RELECTOR RESULTS;LA SALLE PARK SITE

The one thing that we discovered is that your present radar design is based on a logarithmic amplifier and if only one was to make a minor change by going to a linear amplifier you are able to improve the response in quite a dramatic way.Figure 50 shows this.The dotted curve is what you would measure on a present radar system using a logarithmic amplifier and if only one were to change that amplifier unit you can see the improvement that that small change makes to the response of the system.There you see the sort of an effect due to a clutter,a source that was considered to be a target of opportunity,again the log curve is what you would measure on a logarithmic amplifier and the bottom curve is what you would measure on a linear amplifier.Basically,what that really says is,that if I could just change my amplifier design from a logarithmic one to a linear one,which is really ever so simple,the effect can indeed be quite dramatic.

Our current activities, although indeed funds go up and down,are shown in figure 51 and we are committed to this project and our current relate to experiments with the prototype polarimetric radar and I will show you these in a minute.We are working on the design of a suitable tracking filter.We are also looking at the possible use of image processing and advanced polarimetric techniques.

At this point I will show our video of the results.

VIDEO AVAILABLE ON REQUEST

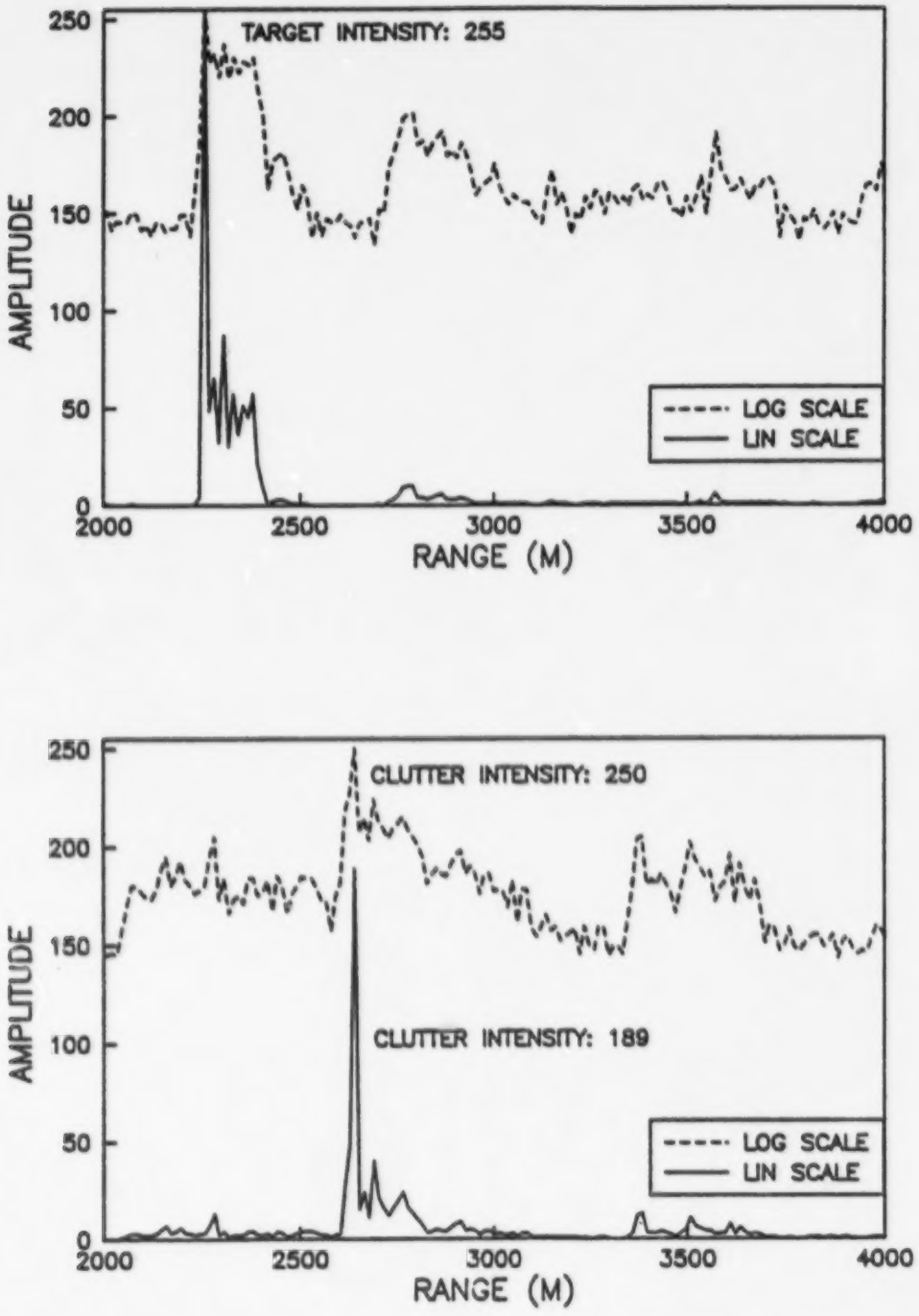


FIGURE 50:LOGARITHMIC VS.LINEAR AMPLIFIER

CURRENT ACTIVITIES

1. EXPERIMENTS WITH PROTOTYPE POLARIMETRIC RADAR
2. TRACKING (KALMAN FILTER)
3. IMAGE PROCESSING
4. ADVANCED POLARIMETRIC TECHNIQUES

FIGURE 51:McMASTER CURRENT ACTIVITIES

Radar Image Correlation Technique:
Dr. G.Austin McGill University:

I have to admit to being a bit of an amateur in marine navigation matters.We have got into marine navigation largely by accident .We have been processing meteorological radar images since about 1948.We got interested ourselves in the detection of icebergs from marine radars using image processing techniques primarily to enhance the appearance of small targets in sea clutter.This was our original motivation.When we did that we put radar processing equipment on ships in order to see icebergs.This led to the interesting experience of sharing the bridge with the captain.We got to see how the ship was run,which I must admit came as rather a surprise to me that the poor man had to run around from the radar to the depth sounder to the chart.All this information was apparently integrated by a pencil and paper on a paper chart which struck me as an incredible way of doing business.I must admit that we were entirely successful in getting back to where we started out from each time we went out so obviously the procedure works.

However it did seem to me that the navigator of the ship was doing an awful lot of unnecessary integration of information in his head.So we talked to some of the mariners involved and said "what about putting all this together in a TV set?".We already have the radar there and it can't be very difficult to put an electronic chart with the radar.Other things like the integrated navigation systems already exist;clearly they should all be put in the same place at the same time.

So we set about building such a thing and it's running in and out of Halifax harbor just at this minute and I'd like to show you what it looks like. I must say that it is my view that there isn't a single answer to any navigation problem.I think the answer is to integrate all the navigation systems.Then you can deploy as many or as few of these precise navigation devices as you need to meet your own particular requirement.For example I can't imagine if GPS becomes available 24 hours a day that any ship interested in navigating through restricted waters could possibly sail without it.Similarly,I can't imagine a ship sailing without a radar.He's also not going to sail without a chart.

The obvious thing to do is to put them all together in other than a paper and pencil analog way and see when you do that,what you've got left.We've had an attempt at that.Here we have an electronic chart(fig.52) of Halifax harbor.The land is painted in yellow.The deep water that is sufficient for the ship,which is the Bedford Institute ship Maxwell.The dark water is of sufficient depth for that ship.The light water is shallow water.The line goes in and out as the tide goes in and out and gets repositioned if you change ship.The little symbol here represents the ships location.The two arrows here,the ships head,and the arrow almost pointing

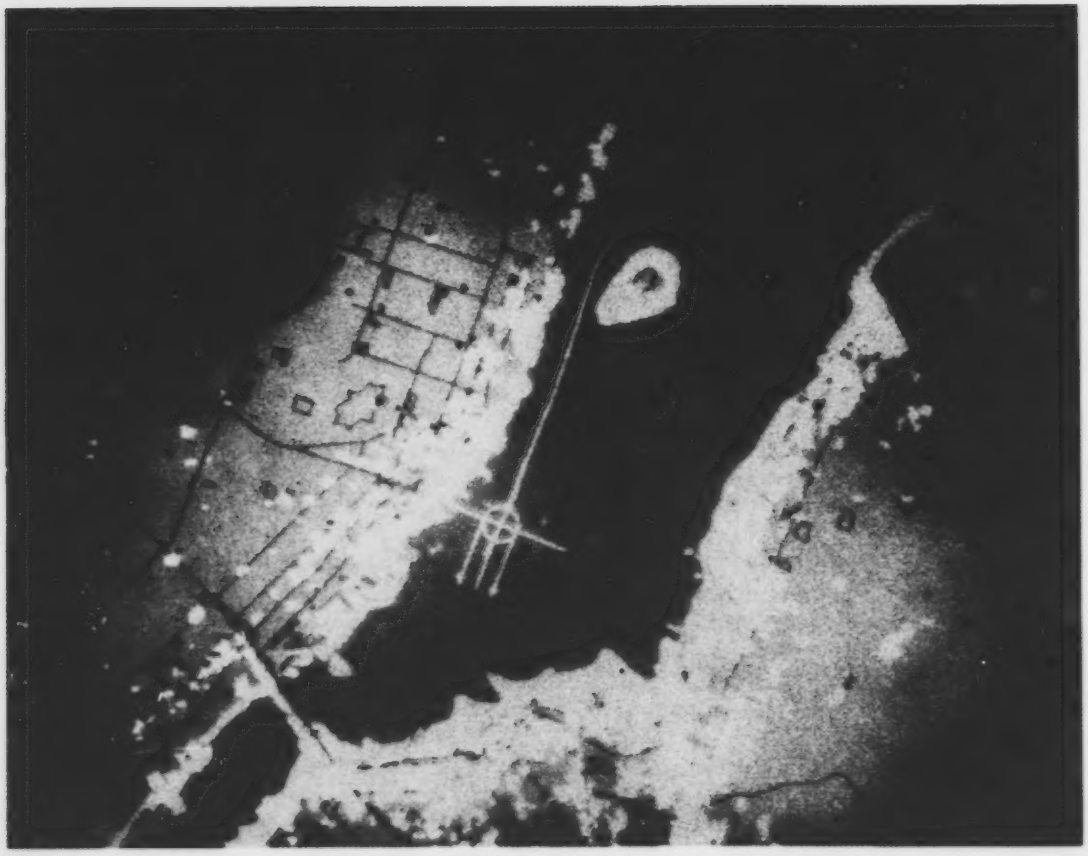


FIGURE 52:ELECTRONIC CHART;HALIFAX HARBOR

backward there,the actual drift of the ship.So that the ship here is substantially stopped in the middle of Halifax harbor.The white rubbish all over the picture is the radar.

So here we have the chart(fig.53),notice this is a north up display.I was kind of surprised when we did this and offered to make this a ships head up display they said that they weren't interested.They wanted to keep their chart North up which struck me as odd but they knew what they were doing, obviously.So all of these are run North up.

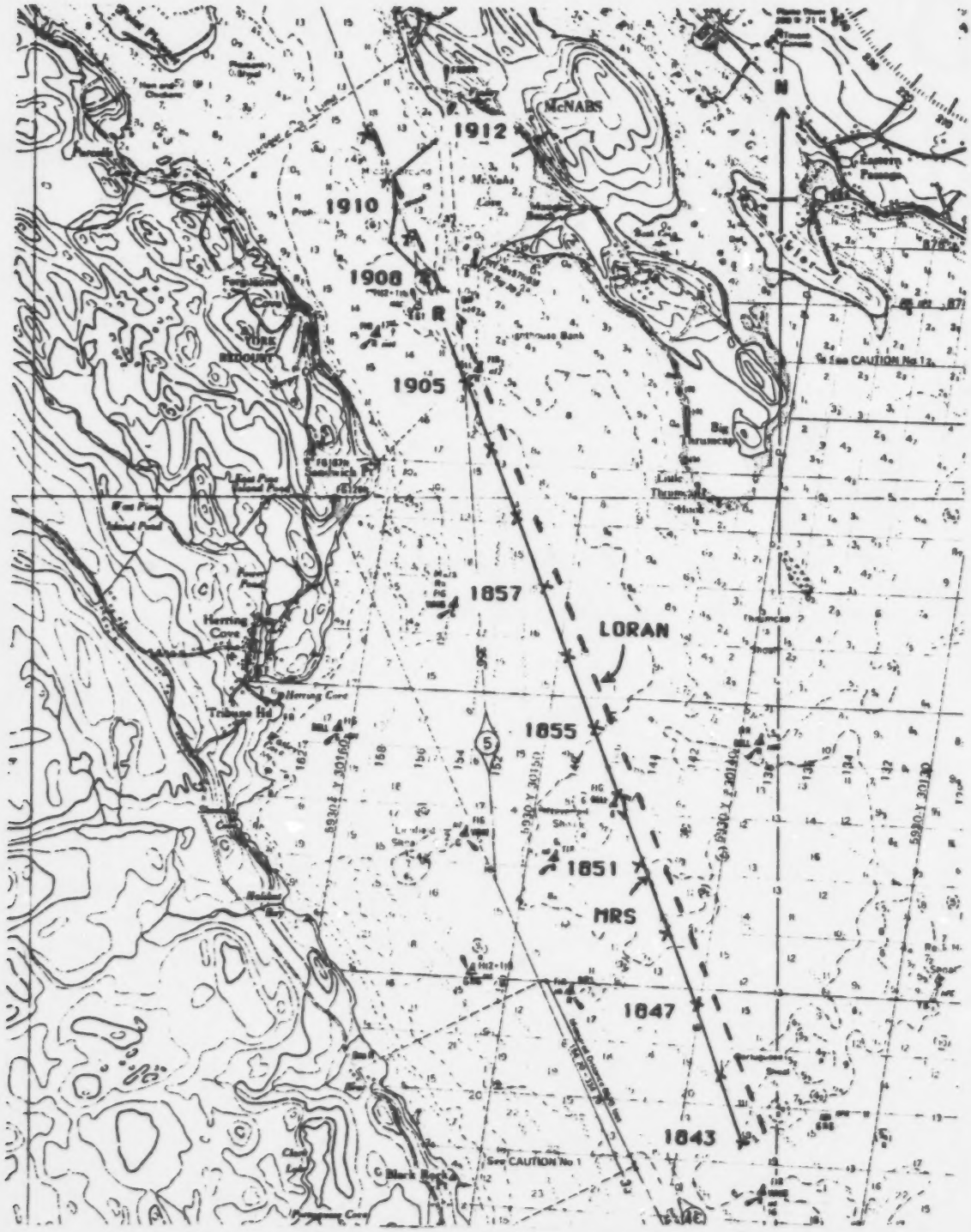
We believe that all the information that is contained in the chart is in this electronic display.The display has been produced by Universal Systems in Fredericton with whom we are cooperating in this experiment.They are doing the charting part of the business.We are doing the radar part.

The positioning of the ship here for this image is actually for the GPS system which is presently only available for one hour a day.So this system as configured only works for the one hour a day when GPS happens to be there.So the positioning here is not by radar but by GPS and the extent to which the radar does not match the coastline is some measure of the error of the GPS.

There is a 20 meter guard circle around the outside of the ship.Here we are actually moving and you can see radar returns from the Angus L.MacDonald bridge.You can also see radar returns from the dock side cranes on the end of the jetties which are, interestingly enough exactly in the wrong place.Someone has dumped the cranes in between the jetties which would leave one to believe that there is a problem there somewhere.Indeed there is, and at this particular moment the GPS system was some 10 or 15 meters too far North and you were able to see immediately by the radar imagery that the automatic positioning system was indeed wrong by that amount.

The research aspects of what we've done has been directed toward correcting them using the radar image.Since the radar image exists, presumably one can correct back the position using the information directly from the appearance of the clutter away from your initial guessed position.This is rather less necessary with GPS than it is with Loran.The Differential Loran-C in Halifax harbor seems to be about 200 meters wrong most of the time which is a rather alarming error going in and out the narrow channels.There is nevertheless the hope of knowing where you are to a few hundred meters.So it isn't the case of having to search all over the North Atlantic to find yourself.

The track here shows the ship is crabbing slightly and you can also see some targets from things other than the land,ships for example.This leads one to believe that you could readily incorporate a collision avoidance system.One of the things which is clear is that if you are going to analyze the radar imagery to implement the cross correlation approach,which I'm going to describe in a minute,you need on the ship a computer with a reasonable amount of



Part of the chart for the approach to Halifax harbour showing ship's track by MRS (full line), Loran (dotted line) and radar fixes (crosses)

FIGURE 53:CHART;HALIFAX HARBOR

brains.Having done that it then becomes possible to use that computer to do a number of other tasks among those being the collision avoidance.

This track of the ship passing through the narrows(fig.54) shows that it is stopped and turning around so can see that it is drifting backwards while facing that way.You can see the relationship between the head and the drift derived from a filter.The nautical charts always have a huge amount of detail on the land,I wouldn't think that it is very likely that it is necessary to know about this particular intersection for the purpose of navigating.So while their objective has been to record all the information on the marine charts on the TV presentation I really wonder about the utility of presenting all these railway lines and things.Obviously the bridge is a highly significant item as are the oil storage tanks but there should be some intelligent selection of data to be presented.

The navigation markers are indicated in little black dots,you can actually put a cursor on the little black dot and it tells you what it is on an auxiliary screen and gives you the information on the fixed aid e.g.light buoy,flashing every three seconds etc.

The way most people would feel comfortable about getting the navigational correction from your integrated navigation system would be to put a joy stick or similar device on the display which can move the radar picture with respect to the chart or I think,more sensibly move the chart with respect to the radar picture.The one good thing about the radar is that it is bolted firmly to the ship.So it is very unlikely that the radar display has wandered off over the side.It seems to me that the chart should be brought back to the radar.That manual adjustment could be entered into the system and taken up into the track.

I don't know what you feel about the fact that we removed all the original soundings.Of course the number of soundings we have in here is spectacularly large and it makes a first order display hopeless on a television tube trying to display all these little numbers.What we have done is made an interpolated surface/bottom map and then we just apply a single threshold which as I said goes in and out with the tide and up and down with the ships draft.The mariners felt that was a good idea since it was one more task they had to do and this thing does it right every time.So on the whole it was considered worthwhile having.

I should now like to turn to the experimental results of using the computer to analyze the radar imagery.I thought I would show you what the radar picture looks like,at least a computer printed out version(fig. 55).This is a digital radar map;it's obviously digital since it's just a lot of little numbers.So obviously the ship is here and these are the returns you get from the coastline going in and out of Halifax harbor.You can see that there is some traffic here but mainly it's a clean image.One thing that you can do with having the computer on the ship is that there is a

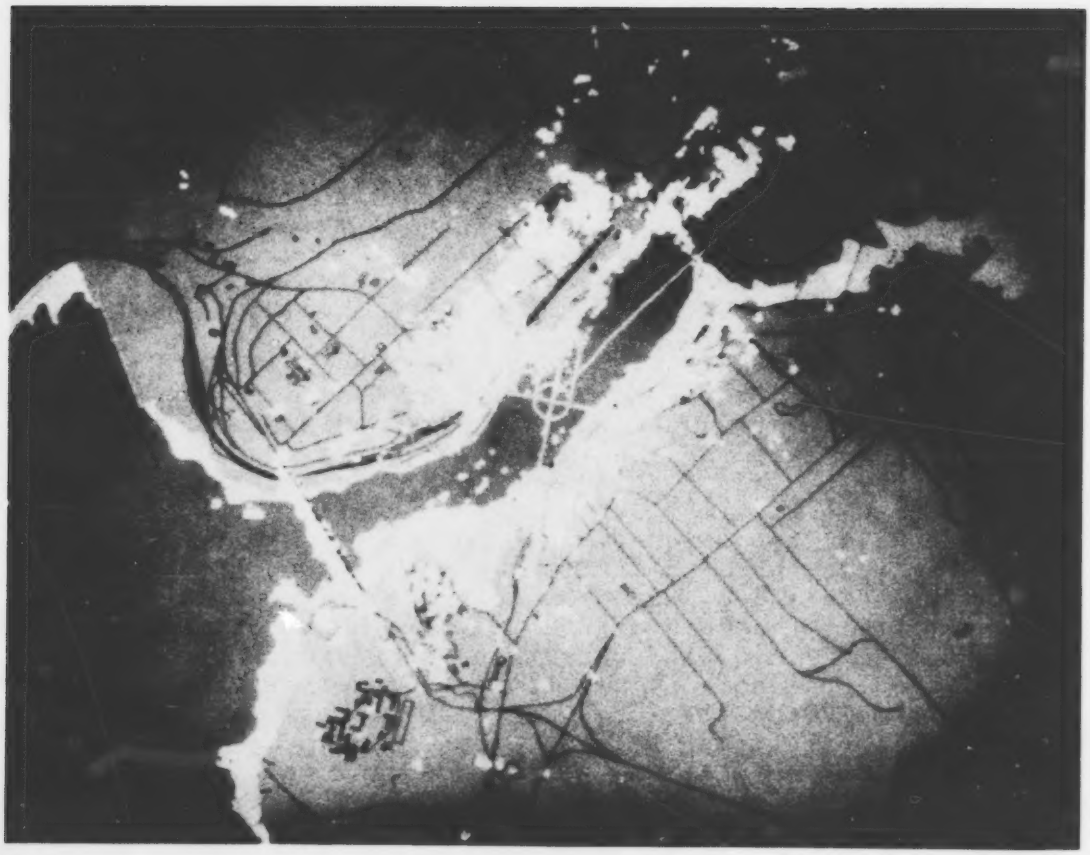
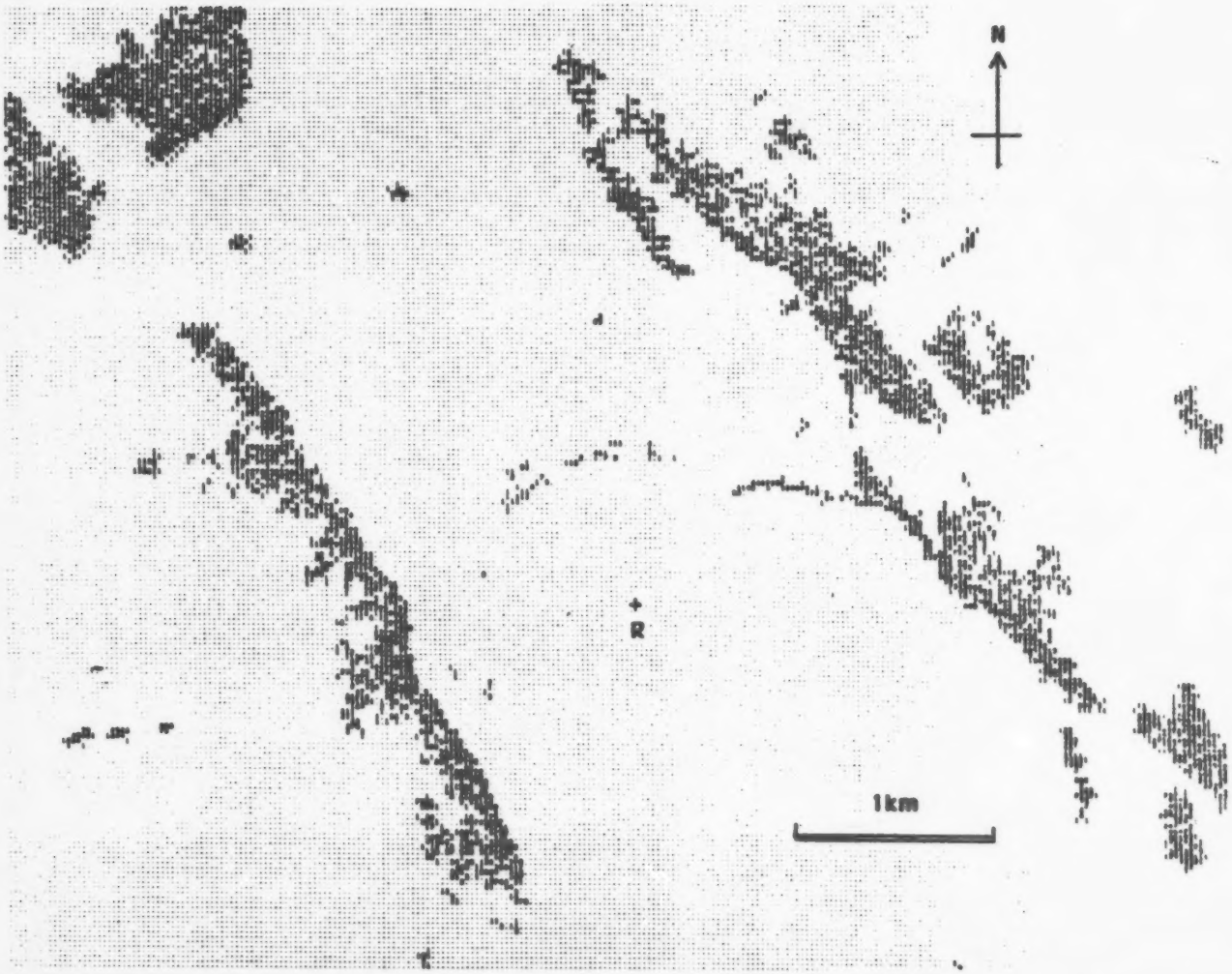


FIGURE 54: TRACK THROUGH NARROWS



Digital radar map. 1 November 1985 at 1906.50 local time. Ship's position is at R on both this PPI and the chart

FIGURE 55:DIGITAL RADAR MAP

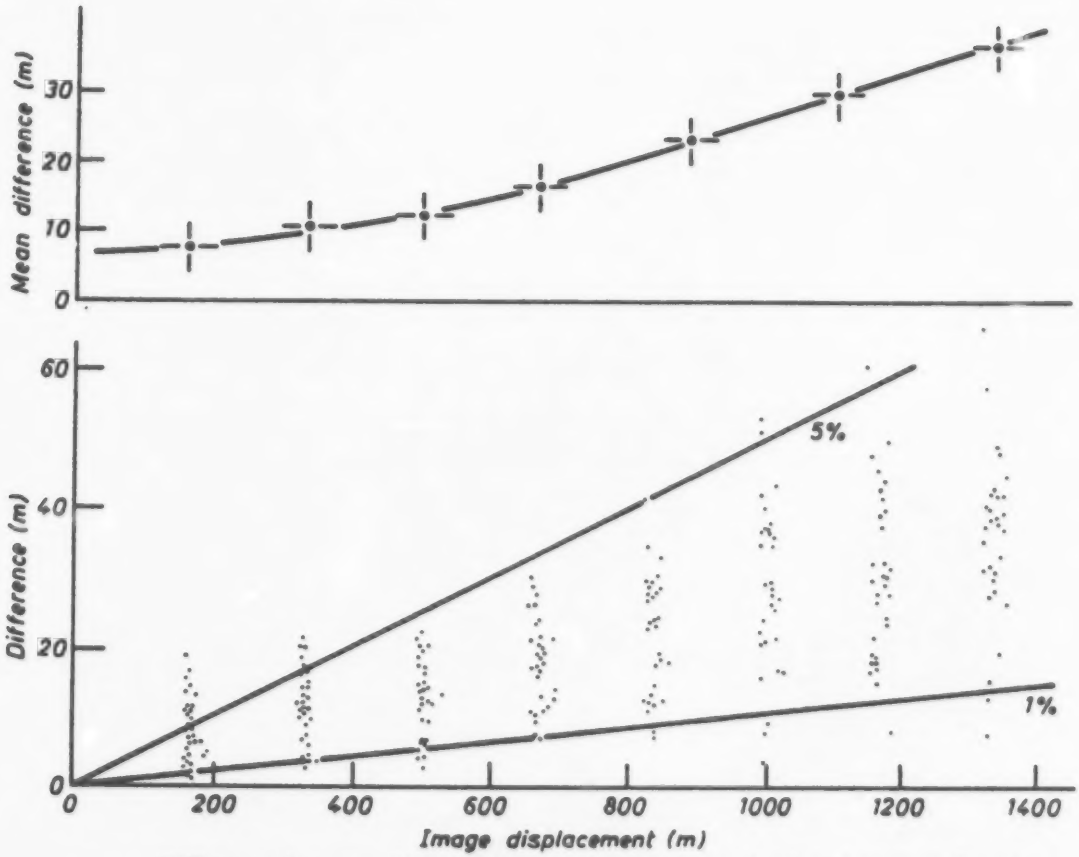
considerable amount of signal to noise clutter reduction calculations that can be applied to the images if you've got a computer that will go fast enough.Certainly picking out things from sea clutter to improve collision avoidance with small targets is one of the things I would be keen to implement in any system one would try to sell.

Our view was that this delineated the coast line reasonably well.Two things that you can do with it are:you can try laying the electronic chart,which I have just showed you,over the top and jiggling it around to see what you can get(that gets you a position);when we did that we found some errors(not catastrophic but bigger than what we would like);therefore we looked at the other alternative;to do two voyages,with the ship(you essentially charge out of the harbor knowing your position,and for this purpose we were lucky to have a mini ranger system for most of Halifax harbor,supplied by the Bedford Institute and good to about 10 meters)so we have radar maps where we know our position to 10 meters.Then we come back again and pretend we don't know where we are and record another set of radar images.Then you can pull out the appropriate image from when you went out and jiggle the two images about on top of one another until they match and then measure the error between the actual position you get from that cross correlation procedure and compare it with what you get from the mini ranger system.

I have some statistics on that experiment(fig.56).I would draw your attention to the bottom curve here,this vertical column is the error in meters,this line along the bottom is the difference in the center position of the radar images in meters.Where you've got a radar image within 200 meters of your actual position then these are the actual errors we got on a bunch of individual tests.You should be aware that the 10 or 12 meters RMS is what the mini ranger has.So it was unlikely that we were going to get accuracies better than 10 meters because that was the accuracy of the input data.

However, you can see that as the distance between the pairs of radar images that you've got increases,then the error slowly increases and once you're up to a kilometer or two it appears to be significantly worse than when you're close in.We would like to do this again with better positioning accuracy on the locations where we take the radar images.This however is difficult since we don't believe that there is very much around that can position us much better than that.So these results go from 10 meters close in to 20 or30 when you are that far apart.

I must point out that some people are surprised that you can position this thing to better than the radar pulse width and the antenna beam width.It isn't obvious that you can position two radar images to better than the resolution of the image.The reason you can do it is really quite clear,if you think about it.If you draw the antenna beam pattern displaced slightly from another,I claim you can



Difference between MRS position and radar determined position as a function of the distance between the origin of the reference radar map and current ship's position for each radar fix. The mean difference is plotted above.

FIGURE 56:EXPERIMENT STATISTICS

overlay on on top of the other to better precision than the width of either of them.If you have two gaussian curves you can obviously put the peak of one gaussian on top of the peak of another gaussian to better than the width of the gaussian(I mean not infinitely better but better).With constructed images we've gone down to a tenth of a beam width or a tenth of a range circle.So it is possible to position things to a fraction of the resolution of the radar.That fraction in ideal circumstances is about a tenth.I am fairly confident that under operational conditions you would be able to get down to a quarter of a beam width or pulse length and retrieve reasonable accuracy.

This then is an automated way of doing what I said the captain could do by jiggling his joy stick to bring the radar into alignment over the top of his chart picture.

This chart data is a rather poor copy of the entrance into Halifax harbor,which is up here.This dotted line shows the track from differential Loran-C and you can see that it is about 200 meters to the right of the true track given by the mini ranger system which is given by the continuous line The radar positions derived by this correlation technique that I have described are actually these circles.To the accuracy you can plot on this chart there is no difference.This is however a low resolution chart.So if you wanted to do it over again on a larger chart you then get the error statistics I had on the previous diagram.It is quite interesting that what happened here is that you have a view angle problem with the mini ranger system as you go through the narrows.The mini ranger position did that which would have proven that the captain was about to drive into the bank here.In fact the radar thing kept on through the channel parallel to the Loran which was showing a significantly smaller error here than it was earlier on.

One of the questions that interests me is that: given that you have accuracies of 10 meters or less on individual fixes,what does that really translate to as errors in the track when you have a proper filtering arrangement applied to the data.There are reasons to believe that the data is random and consequently one would hope that the Kalman filtering type of approach which is used in the system can give you accuracies better than any of the individual measurements.We have not yet done any experiments on that; we would quite like to do so.

So this is where our system is at.We can do correlation certainly for this location.The position seems interestingly accurate,on the order of less than 10 meters and seems limited by the accuracy of the input data.We would like to know how good it really is and there is reason to believe that it might be a little better than that.The main question I want to leave you with at the end of this is:if one could build a system that integrated the electronic chart,the radar,the integrated navigation system(because I don't think we should be playing competitions with these things because I think you need all of them if you are not going to bend

your ship)if you could build this thing,and suppose you could build it for $30,000 would anybody buy it?

One of the concerns I have is that I view the marine navigating market place as rather conservative.Therefore,if one had this magical box that actually performed to this specification and if you spent half a million dollars building a thing of this sort and you put it in the hands of a commercial company who could install it and maintain it;would ,in fact, anybody buy it?

I don't think that I am going to be able to persuade a commercial company to pick this thing up and run with it.I am sure it is a technically solvable problem,we have 90% of the ingredients already.The extra work to finish the thing is not a great deal in the scientific sense.However it is expensive development work because the computers we put in the ship are about $100,000's worth (this is not the final format in which the system is going to finish up).If one is prepared to do the work you can probably get the final product down to $30,000, if you're optimistic but I have great doubts that if we did that that we would be flooded with mariners who wanted to buy it.They might regard it as just another childish toy that they would studiously disregard as they navigate in the manner that they have always done.So I would like to get a feed back from you gentlemen,who are professionals in the field,as to whether this is going anywhere or whether I would be better going off playing with meteorology which is what I do the rest of the time.

There are a couple of scientific papers published on this project in the Journal of Navigation.If you would care to leave your name and address I would be glad to send you copies.

AFTERNOON SESSION

Electronic Charting:
Mr. H.Lanziner Offshore Systems Limited.

I should just like to say a few words about who we are,what company we are,for those of you who have not heard of us.Offshore Systems Limited is now the parent company of a company called Offshore Survey and Positioning Services which was formed in 1977 and was entirely at that time and for many years thereafter a service company.The reason why this is important is that we as a service company have had a lot of experience,real world experience in the field of positioning.In those daysit was with drill ships,supply vessels and ice breakers in the Beaufort sea.That was our main arena,the Beaufort sea when it started up with Dome Petroleum in 1976.

We went through a variety of positioning tasks in that time from moving drill ships on and off drill sites to doing site surveys in channels, harbors and bays to doing acoustic positioning for the variety of the tasks that they required.In our activity in the Beaufort we were required to produce a channel navigation system in 1979 that could be used by relatively inexperienced people since they didn't want to have an operator on board all the time when they were only travelling in and out of these channels on the average of once a week.

The real challenge there was to produce a system that could actually be operated without any major training sessions by literally just turning a switch on and an electronic chart would come on the screen and show them where they were in relation to the shore and with relation to the channel.We gave them cross track information to show them how far off they were from the center of the channel.The challenge there was to make it foolproof.The first year,something like 80 to 85% of the problems were finger troubles and had little to do with either the hardware or the software.It was simply a matter of making it foolproof and we learned a lot.

I shall show some slides and talk to them to let you know that we do have the field experience.We have worked with HF and MF systems and have a lot of experience with microwave systems such as mini-ranger, DelNorte,micro fix,etc.

The first display that we used in the Beaufort in 1979(fig.57) shows the major number that everyone was interested in,apart from the graphics display,which was the cross track information.The"S" here stands for starboard the "P"for port and the vessel is the shape of a little triangle.We had two scales:one was 18 kilometers across which showed the whole bay including the channel,the harbor and some of the shoals;the other would show an inset of 1000 meters which would give a little more detail of the dredged

area.This is a very shallow bay,about 5 to 6 meters with a channel dredged to 10 meters or 12 meters in some cases and a hundred meters wide.

When you have moving ice or strong winds and you have large vessels like drill ships or ice breakers moving in and out of there it becomes a pretty challenging task.The system at the time was monochromatic;we showed some distances and the true grid position or the geographic position.We showed distance to the next way point and the bearing of the next leg to that way point and the distance to the previous way point and the bearing on that going in or out of the channel to show what their next segment would have in the way of bearings or distances.

In 1982,since graphic systems were coming along quite rapidly and high speed graphic displays with much higher resolution were becoming commonplace in 1982 to 1983,we switched to a color graphics system where,of course you can code a lot more information than you can on a monochrome display(fig.58).We have a similar system on BC ferries where we experimentally had the system on and off the ferries for about a year evaluating the performance and the requirements and getting an input from the operational people.The

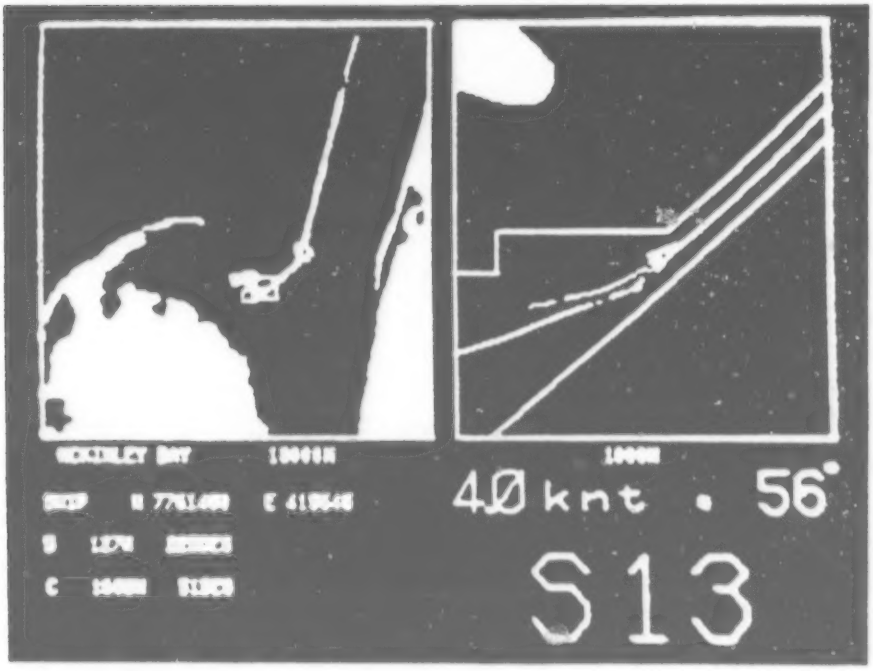


FIGURE 57:EARLY (1979) DISPLAY

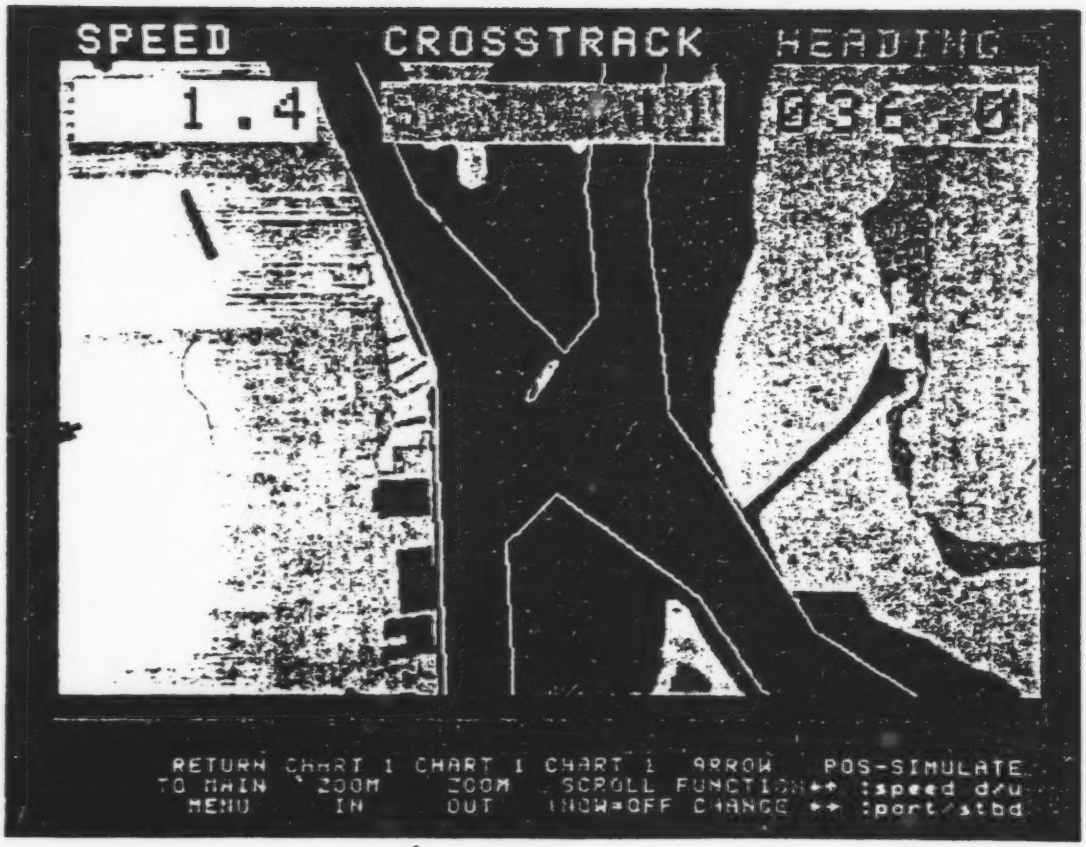


FIGURE 58:COLOUR GRAPHICS DISPLAY

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displays are very similar to the monochrome system but are of higher resolution and in color.

In 1984 and 1985 we decided to get serious about this business.Whereas in the past we had only been doing it as a service company we decided we wanted to actually produce these systems.We felt there was a market for this type of equipment and we formed Offshore Systems at that time with the purpose of designing and manufacturing electronic chart systems.

This is the current version of our system(fig.59) using a 19 inch monitor with tremendous flexibility as far as screen displays go.It allows the user to change to different size screens he can scale up and down; he can display different alpha-numeric characters and the user can do this without having to be a programmer.One very important aspect of this is directed syntax.We've added these keys onto the bottom of the screen and in these windows you can see the function of these keys.So,for example if you want to zoom in and out or if you want to use different scales or if you want to invoke various functions you can do that very easily without having to have a regular key board in front of you or without having to really know any thing about the equipment other than that which is displayed to you below the screen.

Typically we have a main menu giving you the types of displays(fig.60)available:course to steer,up,which means that the chart is always rotated so that the course to steer is up on the screen;manual course,up,so that you can select any bearing or heading up;automatic course up where the chart rotates automatically as the ship turns;hydrographic line calculations etc.There are selections for four charts and two charts and so on.

The example here(fig.61)is the full screen chart with little alpha information actually little windows superimposed onto the chart itself giving;speed,cross track information,and ships heading.Figure 62 shows another typical display with large characters(some people prefer this because they can see it from the other side of the bridge) again with two scales 5000 meters across,here and 750 meters which represents this window here and you can also see the cross track information.This also shows a tow fish.It can show additional bodies such as towed bodies behind the ship or other vehicles such as submarines on the screen and we can display their position.All of this has been designed to be user configurable.

Some of the functions available are: the ability to shift chart scales,scrolling screen (as the vessel moves,it,sits in the center of the screen and the chart scrolls by)or you can stop scrolling and move the scene frame to frame.You can set cursors and markers.One example here(although not what you would normally use)demonstrates three sized charts one with North up ;one with a manually fixed course up and one with ships head up.This(fig.63) shows a typical search grid in this case Port Angeles off

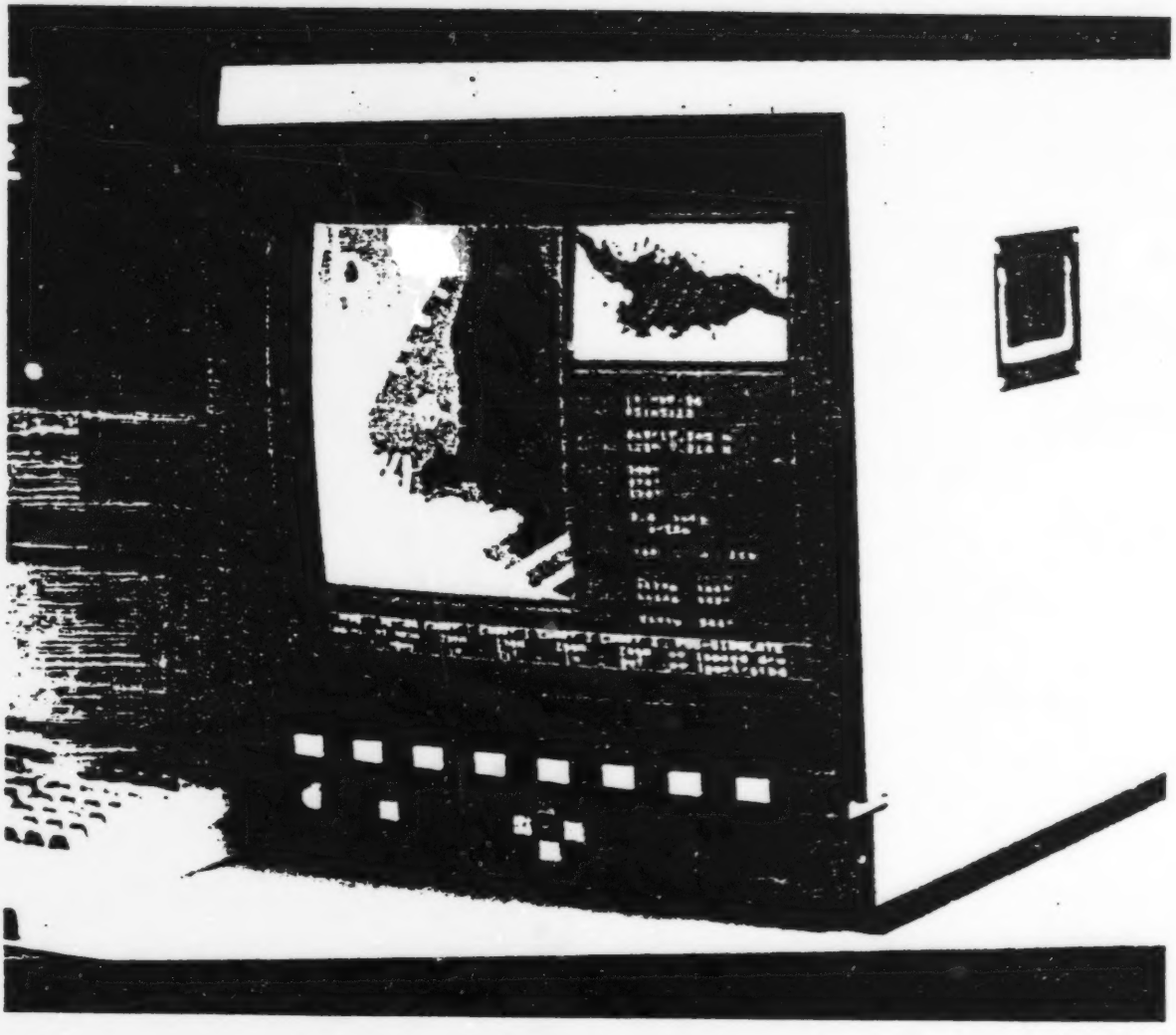


FIGURE 59:CURRENT SYSTEM

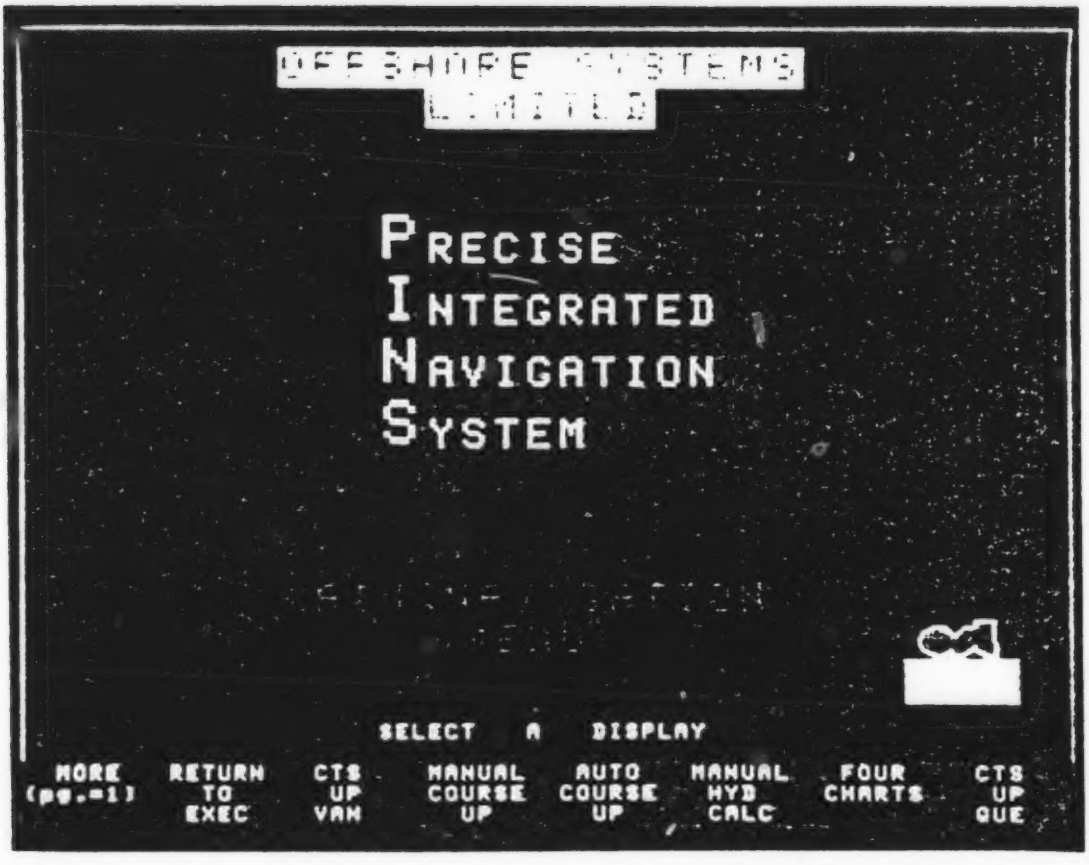


FIGURE 60:MAIN MENU

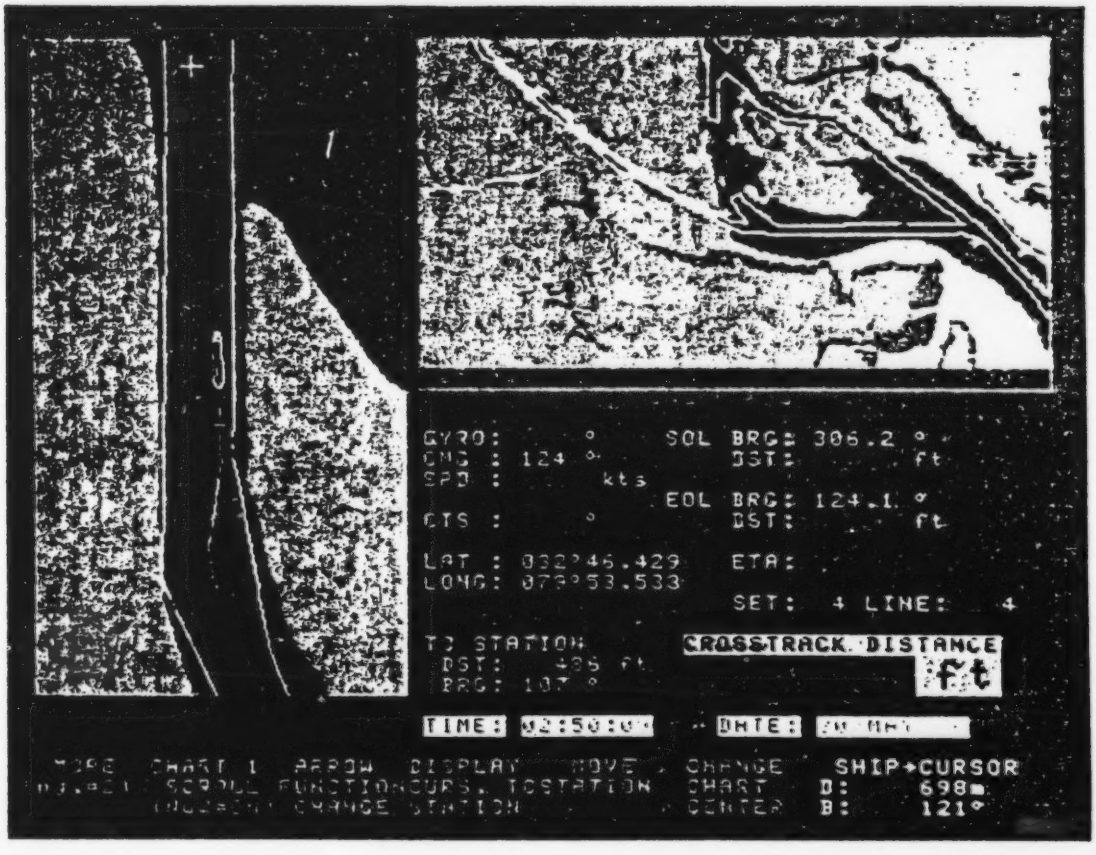


FIGURE 61: FULL SCREEN CHART

FIGURE 62:DISPLAY;LARGE CHARACTERS

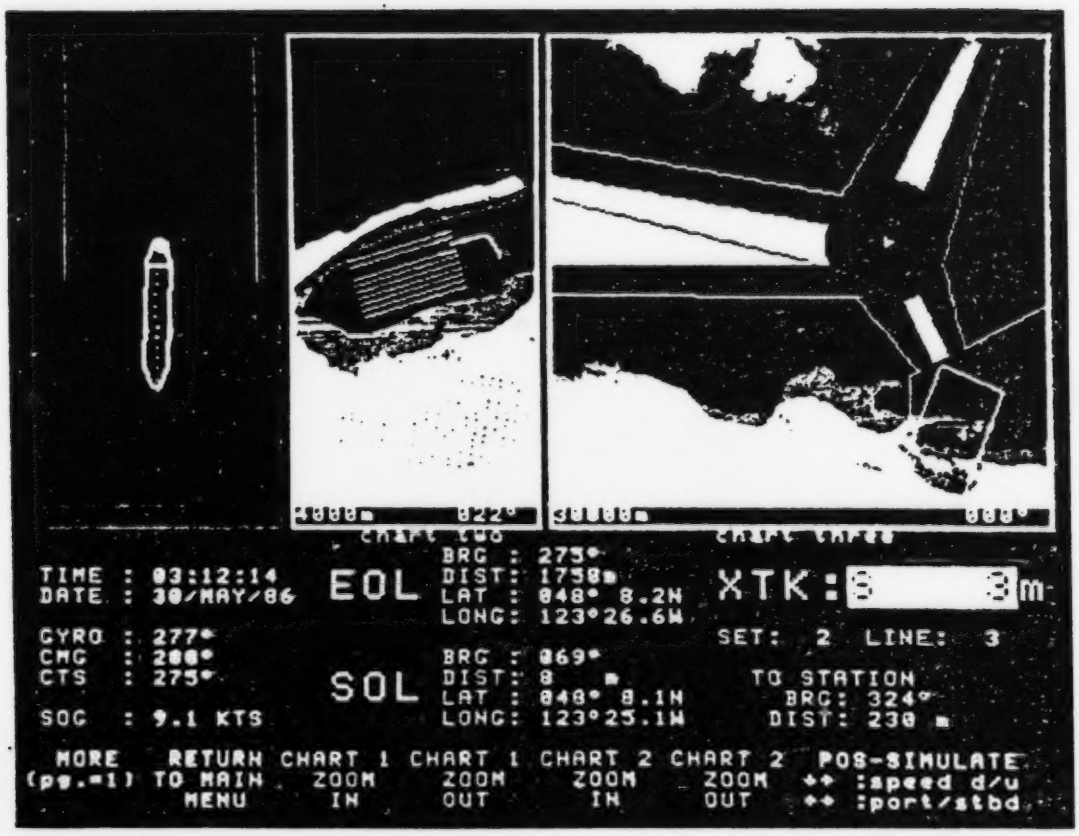


FIGURE 63:SEARCH GRID

the Washington coast.You can see Juan de Fuca strait with the traffic separation zones and the border,the town of Port Angeles and the search grid.This menu here can be increased by accessing what is in the window and you can switch from menu to menu in an almost endless combination.We are showing distances from start of line,end of line,gyro compass course made good,any number of things.

I think we make available to the user something like 70 variables that he can select from.There is a help feature using one of these keys so if you are stuck and don't know what you should press next or why you should press it next it will explain to you what it is.One of the features here is what we call the ghost ship you see the red outline and the white outline and the ships track.We permit the user to select a predicted ships position based on his present course and speed(in this case ten seconds).He can select any time interval projected ahead to see where the ship will be.We also have a vector display which shows rate of turn and a true vector if the ship is crabbing in the current.

We also have an error ellipse which is based on statistical monitoring by the computer of the range data or the positioning data as it comes in.It also takes into account gyro compass or speed logs or any number of navigation aids on the ship including sounders.We also did a project for the US Navy for mine counter measures work where they were very interested in where the sonar tow fish is located and the safe boundaries for their vessels.We use a cursor to measure range and bearing.

Another feature is alarms.Normally we use color to define specific things with the actual definition on one side in color and the variable on the other side (although they are selectable by the operator)then we have alarm conditions that can be set for any time interval distance interval,bearings etc.For example if your distance exceeds a certain limit you can set two levels of alarm.It will change one color to say magenta after five seconds and then after ten seconds it would turn to red.These alarms are available for all the variables.They can be defined by the user without him being a programmer.The vector display can indicate the rate of turn of the vessel.

We have a system on board the Marine Atlantic vessel Caribou which you heard Dave Williams describe earlier.There are two independently controllable monitors.The display for Port Au Basques has a few added features.There is fix quality feature which displays the 95% probability ellipse based on the semi major axis of the error ellipse.Entering Port Au Basques harbor it would show typically one or two meters.It also shows which stations are active.We can show distances to points along the route.We can select points such as Vardy's Island,Cove light etc. These will change as the ship progresses and you will be given a continual readout of what the distance is from the ship to the selected point.

We can also overlay the radar image electronically on top of the chart.It becomes very easy to see from the two images where they are not in alignment.We heard earlier from Dr.Austin about the pattern matching or image matching capabilities and this is a very useful feature whether it is pattern matching or image matching or reflectors it allows you to get a higher accuracy out of a particular system when you have a radar positioning capability.

One of the problems we face when we sell our systems is that we repeatedly run into the cost and the problems associated with microwave or radio positioning systems.Maintenance(you heard Dave Williams speak earlier about that)is a problem.Anyone who has used these systems knows that they are prone to failure,to weather to storms etc. and you have to maintain them and that is costly even apart from the capital cost of the systems.We have looked at great length and at other means and sources to get an accurate positioning input into our display.

All that I have discussed so far is the display and its capabilities.Apart from the display we also have a true integration of navigation inputs.We can input speed logs sounders, gyro compasses ;several devices at the same time.We can use an MF system,Loran-C or tie it in with a satellite system.We have done most of this in the real world, sometimes under severe conditions.So we not only have a very nice display for a variety of system inputs but we also have an integrated system and we feel that that is quite important.It took a lot of our time and money to make those integrations workable and to allow us as broad an input selection as possible for most of the standard systems.

However,to come back to my comment of a few minutes ago we were looking desperately for something better than that and something that would give us position to a reasonable degree of accuracy such as is required in the St.Lawrence.By doing that we spoke to people at McGill University and to people at McMaster University about their ideas and were quite intrigued by the reflector concept,having read the PRANS report.We started to investigate that a little closer and one of the major points I am trying to make today is that recently we ran across a system that was developed over the last few years that is based on radar positioning.This system uses natural reflectors at the present moment;it uses only what is out there,docks,pilings,buildings etc.It is quite sophisticated in its approach by coding all these various shapes it uses them in a combination algorithm that comes up with a position.

I went to see a demonstration of the system recently and spent the better part of a day riding on a vessel over a several mile area.I insisted we use a microwave system alongside to compare what the accuracy of the system actually was.The manufacturer claims something like two meter position accuracy.Now,most of you like I would say,impossible!and certainly while I cannot vouch for that

accuracy,during the many hours that I was there we never had any interruption of the position based on this radar system and we never got outside of 15 feet radius from the DelNorte microwave system.I was very impressed with what I saw.We were outside a city in an area that did not have big built up reflectors.The conditions were ideal,I believe ,for this type of system.I just checked with a government agency that has been evaluating this system for the last four months to see whether it is valid for hydrographic survey and they have just advised me that they are purchasing the system.their requirements are 2 to 3 meters.

To go a little further I talked to these people about moving the system to Vancouver to evaluate it.Which they responded to immediately by offering the system for two weeks and that they would stand behind their specifications.I enquired as to how well their system worked in the presence of buildings.They replied that there were some problems but they felt that they could overcome those problems.I mentioned the reflector technology developed by McMaster University and they were very exited and considered that the polarimetric reflectors would solve all the problems they had in built up areas and that by using them they could build a totally reliable system.I must admit that although I only spent the better part of a day with this company I was most impressed.

The point I am trying to make is that we have developed the electronic chart to the point where we have sold a number of systems.We have systems in operation with Marine Atlantic,Ontario Northland,a commercial company on the West coast,the Canadian military and most recently the US military.We are building systems for the DSRV the deep submergence rescue vehicle project.We have also sold a system to Vancouver port corporation where a similar system based on shore is used to monitor vessels in the harbor.So we have systems in the field ;they are real.What I saw in this demonstration I described is real.I think that with that and something like the McMaster development,which ,from what I saw today I don't need any more convincing,I feel we have a potentially fantastic package.These things are all real,they exist now,and if they are put together in a properly funded development they could revolutionize the navigation industry.

Now, cost wise, to address the issue Dr.Austin raised earlier I don't know what such a system will cost in the end but let's assume $30,000.From the market studies we're undertaking right now we don't think that's much of a problem.We're not dealing with the pleasure market right now,later on we will,and our basic system sells for $50,000 to $60,000 without microwave inputs(which puts it up to $200,000) and there are markets for our system right now.

Comparative analysis of systems:
Mr. D.Ball,Canadian Astronautics Limited.

First,a little bit of advertising for those of you who may not have heard of Canadian Astronautics,we are a small Canadian company of about 200 people.We are heavily into engineering,most of our people are engineers.We are located in the west end of Ottawa.You have probably heard about us in space work.We are in competition with such companies as SPAR.Our most well known work is our ground stations.We build SARSAT ground stations to receive signals from the search and rescue satellite.That is where we got our start;we have built several;and they are distributed around the world.As a spin off from the space business we get into all kinds of things and right now we manufacture radars and sonars;we do image processing;we do all kinds of engineering jobs.

We were asked by TDC to address the question:"which system is the best?"In reality there is no "best " however we were forced,in our inquiry to select a system and cost it.What we said was that we will select a system to meet this particular requirement.This does not mean that the system will be the be all and end all for all requirements. In fact I think Dr.Austin said it best when he said integrated systems, the best for each application is the way to go.

What I'd like to do is give you some of the advantages and disadvantages of the approach and because TDC asked us I will give some costing data on what we considered the "better " system in this application and there are some other possibilities that we can explore later on in our discussions this afternoon about 'what other ways we might have gone for other applications.

The things that we concentrated on to do this trade off study were the first three items(fig.64).The others were all important we said any system has to have those but we said the first three can serve as the basis of a trade off.The first one is absolutely essential;the second highly desirable;the third will probably end up being the deciding factor.

You have seen this slide before (fig.65).For this application we removed the microwave transponding systems(despite the fact that they have demonstrably proven their value) because they were too expensive and because of the short base line.

We looked then at correlation radar,polarimetric radar and differential GPS(fig.66).What do I have to have on the ship for a correlation radar?We have to have a ships radar,a correlator and a storage unit and on the shore we need nothing.For the polarimetric radar we need a ships radar modified with an extra receiver,a modified antenna and on the shore we need a number of passive reflectors.We estimate that 314 would be necessary down the length of the Seaway

* SUFFICIENTLY ACCURATE
* TECHNOLOGY PROVEN OR WELL KNOWN
* REASONABLE COST
* COMPATIBLE WITH EXISTING SHIPS RADAR
* COMPATIBLE WITH MARINE NAVAIDS (LORAN,GPS,ETC.)
* COMPATIBLE WITH ELECTRONIC CHART
* ADEQUATE FAILURE RESPONSE TIME
* ADEQUATE HEALTH STATUS CHECK
* EASILY USABLE BY SHIP'S CAPTAIN

FIGURE 64:SYSTEM REQUIREMENTS

1 RADIO RANGING SYSTEM (UHF OR MICROWAVE)
2 SHIP'S RADAR WITH TRANSPONDERS
3 SHIP'S RADAR WITH POLARIMETRIC REFLECTORS
4 DIFFERENTIAL GPS
5 SHIPS RADAR USING IMAGE CORRELATION

* SYSTEMS 1 & 2 TOO EXPENSIVE
  -REQUIRE POWERED SHORE-BASED UNITS
    * INSTALLATION
    * MAINTENANCE
    * POWER SOURCE

FIGURE 65:TECHNICALLY ACCEPTABLE SYSTEMS

REQUIREMENTS UNIQUE TO EACH APPROACH

APPROACH	SHIP-BASED EQUIPMENT	SHORE-BASED EQUIPMENT	NOTES
Correlation Radar	- Ships Radar - Correlator and Storage Unit	None	Stored Radar Image Needed
Polarimetric Radar	- Ship's Radar, modified with extra receiver - Modified Radar Antenna	- 314 passive polarimetric reflectors	
Differential GPS	- GPS Receiver - Differential data receiver	- 2 differential sites - Dedicated radio link —	Integration with ships radar is optional

FIGURE 66:COMPARISON OF SYSTEMS

S. No.	DIFFERENTIAL GPS	POLARIMETRIC RADAR	IMAGE CORRELATOR
1	Dependent on U.S. government programs	Independent	Independent
2	Not available until 1991	Technology available	Technology available
3	No multipath effects	Multipath effects minimized by spatial diversity	No multipath effects
4	Weather effects not serious	Rain clutter minimized by cross polarization	Rain clutter minimized by sector processing
5	GDOP acceptable with full set of satellites	GDOP reduced by using a large number of reflectors	Aspect angle effects minimized by using adequate number of reference images
6	No interference expected (data link must be licensed and dedicated)	Interference from other shipborne radars rejected by pulse-to-pulse correlation	Interference from other shipborne radar suppressed by pulse-to-pulse correlation
7	No clutter problems	Cross polarized clutter effects reduced by differentiating between point & distributed targets	Clutter used for image correlation. Seasonal clutter variations could be a problem, solved by seasonal reference images

FIGURE 67;COMPARISON TABLE

S. No.	DIFFERENTIAL GPS	POLARIMETRIC RADAR	IMAGE CORRELATOR
8	Time jitter minimized in receiver design. Bias errors corrected in differential mode of operation	Time jitter checked during calibration and maintenance. BITE used to detect problems	Time jitter less critical. BITE used to detect problems
9	Independent of pulse shape	With leading edge detection, good accuracy is obtained	Pulse shape less critical.
10	Blockage minimized by locating antennas sufficiently high	Blockage minimized by using additional reflectors	Blockage effects minimized by sector processing of image
11	Satellite identification is available and is used in the processor	Target identification not available. Tracking system must take this into account	Target identification not applicable. Performance can be improved by adding reflectors or transponders
12	Differential stations and transmitters require both power and maintenance	Maintenance of non powered reflectors minimal. Radar periodically calibrated to ensure accuracy	No shore sites to maintain. Radar periodically calibrated to ensure accuracy

FIGURE 68: COMPARISON TABLE CONTINUED

S. No.	DIFFERENTIAL GPS	POLARIMETRIC RADAR	IMAGE CORRELATOR
13	Redundant receivers can be used on the ship	Failure of ship's radar makes the system unusable	Failure of ship's radar makes the system unusable
14	Portable, stand-alone system, easily installed	Requires modi-fications to ship's antenna and ship's radar	Interfaces to existing ship's radar
15	Minimal pro-cessing complexity outside the receiver	Moderate comp-lexity in the processing of radar signals	Greater complexity in the processing of radar signals
16	Operation of differential stations requires licencing	No licencing problems	No licencing problems

FIGURE 69:COMPARISON TABLE CONTINUED

POLARIMETRIC RADAR

ADVANTAGES

- USES EXISTING SHIP'S RADAR
- UTILIZES NON-POWERED SHORE BASED REFLECTOR
- INTEGRATED WITH DIGITAL (REAL TIME) RADAR DISPLAY
- COMPATIBLE WITH GPS

DISADVANTAGES

- REQUIRES MODIFICATIONS TO SHIP's ANTENNA AND RADAR
- NO POSITIVE TARGET IDENTIFICATION
- MORE EXPENSIVE THAN CLUTTER MAPPER & DIFFERENTIAL GPS

FIGURE 70:POLARIMETRIC RADAR

DIFFERENTIAL GPS

(GPS - Global Positioning System)

POTENTIAL ADVANTAGES

- BASIC ACCURACY IS HIGH
- MINIMAL SHORE BASED EQUIPMENT
- 'LOW COST' RECEIVER

POTENTIAL DISADVANTAGES

- NOT OPERATIONAL UNTIL 1990
- REQUIRES DEDICATED RADIO DATA LINK ON SHORE
- RELIABILITY QUESTIONS
  - POSSIBLE OUTAGES (SATELLITE FAILURE)
  - INADEQUATE "HEALTH" MESSAGE RESPONSE TIME (10 SECONDS)
  - NON-CIVILIAN CONTROL

FIGURE 71: DIFFERENTIAL GPS

CLUTTER MAPPER

ADVANTAGES

- NO SHORE BASED EQUIPMENT
- USAGE OPTIONAL
- INTEGRATED WITH DIGITAL (REAL TIME) RADAR DISPLAY
- COMPATIBLE WITH GPS
- LEAST EXPENSIVE

DISADVANTAGES

- SENSITIVE TO TIDELANDS
- SENSITIVE TO ICE PILE-UP ON SHORE
- NEW LARGE MAN-MADE STRUCTURES HAVE TO BE ADDED TO REFERENCE

FIGURE 72:CLUTTER MAPPER

CLUTTER MAPPER RADAR

* IMAGE MATCHING
* CORRELATES CURRENT RADAR IMAGE WITH STORED REFERENCE IMAGE
* REFERENCE IMAGES (approx. 300) TWO PER NM ON AVERAGE, STORED ON COMPACT DISC
* CALCULATED POSITION DISPLAYED AS OVERLAY ON A DIGITAL RADAR DISPLAY
* USES EXISTING X-BAND SHIP's RADAR
* REQUIRES NO SHORE-BASED EQUIPMENT

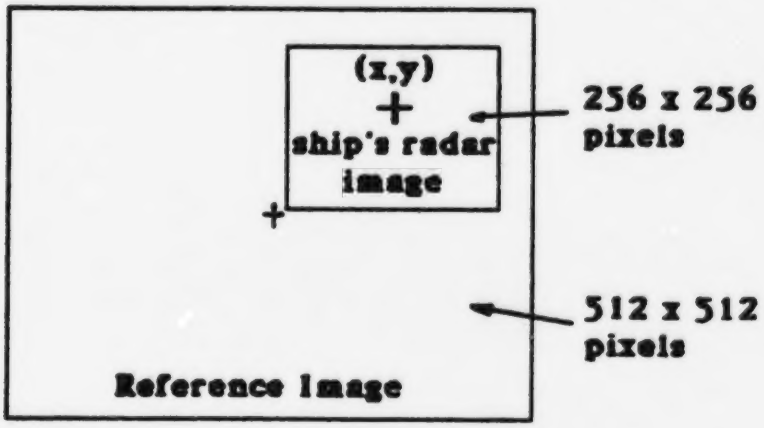
FIGURE 73:CLUTTER MAPPER RADAR

POTENTIAL PROBLEM AREAS

- HEAVY RAIN
- BLOCKAGE
- ICE PILE UP, WEEDS
- OPEN WATER
- TIDES

FIGURE 74:POTENTIAL PROBLEM AREAS

IMAGE CORRELATION



1. **Using estimated position co-ordinates (x,y), compute correlation between the radar image and reference image.**

2. **Shift ship's radar image by one pixel and two pixels in both x & y directions and compute correlation coefficient for each shifted position.**

3. **Prepare coefficient matrix and compute its centre of gravity to obtain exact location.**

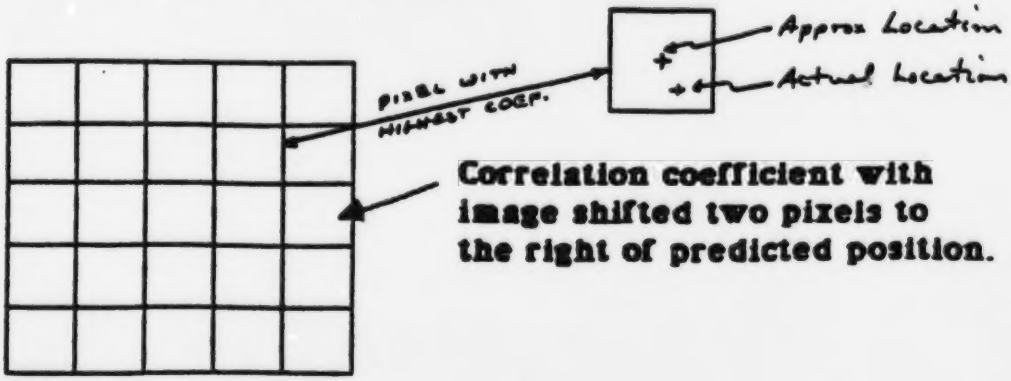

Approx Location
Actual Location
PIXEL WITH HIGHEST COEF.
Correlation coefficient with image shifted two pixels to the right of predicted position.

FIGURE 75: IMAGE CORRELATION

COMPUTATIONS

- REFERENCE IMAGE SIZE = 512 x 512 = 262 K PIXELS
- TOTAL MEMORY CAPACITY REQUIRED FOR 300 REFERENCE IMAGES
  - = 78.6 M PIXELS
  - = 0.31 GBITS (FOR 4 BIT PIXELS)
- CORRELATION COEFFICIENT COMPUTATION
  - 256 x 256 MULTIPLY AND ADD
- FOR 5 x 5 COEFFICIENT MATRIX, - 25 x 256 x 256 (1.64 M) MULTS & ADDS REQUIRED

FIGURE 76:COMPUTATIONS

spaced about one and one half per kilometer.Differential GPS requires a GPS receiver on the ship,a differential data receiver on the ship and on the shore you require two differential(possibly one)and a dedicated,highly reliable communications link(dedicated because we are talking about a real time system)Two notes:with the correlation radar you need a stored image and with the differential GPS it would be highly desirable to integrate it with the radar because GPS does not tell you about moving objects.The comparison tables in figures 67,68,and 69 elaborate on this.

The order in which I put these is totally random.We already know something about polarimetric radar.Its advantages and disadvantages are shown in figure 70 The key issue I think is the non powered reflector which makes it cost effective.

We wanted to eliminate differential GPS off the top because it is a complex system.A lot of things are planned ,conceived,conceptualized a lot of intermediate tests are available but we don't have it.However,it is real and we are faced with the fact that it will be up there one day and we had better look at what the potential of what the system can do for us.The main advantage(fig.71) is that the basic accuracy of the signal is high.With the C code they are talking about degrading the signal to 100 meters.With differential GPS you are looking at a few meters with no problem.The "low cost receiver" is based on the market predictions of the GPS advocates.The dedicated link also provides some problems and the health message response time of ten seconds is marginal for this operation even when the GPS people do get it down there from what I understand is a warning time at present of twelve minutes or more.We think a warning in the two to five second area would be much preferable for precise navigation in this application.A key issue is non civilian control.

I've switched to the word Clutter Mapper from image correlation.The reason will become apparent as we discuss it further but for the time being assume that clutter mapper means the same as the image correlator discussed by Dr.Austin.Figure 72 shows the advantages and disadvantages.

We concluded from this that the clutter mapper is the best way to go.It is the least expensive and offers all the features.So what I would like to do is press on and tell you a little more about the clutter mapper and what it might do.We are talking about image matching.Specifically we are talking about matching an image taken from a radar months ago with an image taken today.Figure 73 shows this.Our study showed that about 300 reference images would be necessary about two per nautical mile.CD's now have gigabytes of storage capability.

Figure 74 shows problem areas.We feel that heavy rain,which affects all radars,could be handled by using correlation in a zone approach where you correlate six out of seven or seven out of nine etc.since heavy rain tends to be concentrated in one area.Blockage

again should be answerable by a zone approach.Ice pile up and weeds might be solved by masking approach where you mask water areas don't do your correlation where such problems might occur.Open water? mask it.Tides are real but we don't have tides in the St.Lawrence.We do have waterlines that shift but we don't think that will pose a problem because both shores are visible at all times so we have a symmetry where you only have one shore this would be a problem.One could see handling this problem by having more stored images but then you would have the problem of how you select them and the time of day and reference to the tide charts and things get a little more complicated.Tides are a problem and it is here that you would think of tying in the polarimetric type of radar to solve the tide problem.

How does image correlation work? Figure 75 addresses this.Basically what we are doing is taking a big reference image and a small radar image and we are assuming that when we start we know roughly where we are.Because if you are going to search this whole area with a reasonable sized computer it could take you a long time.We are proposing that you want a reasonable knowledge of where you are if you want to solve this in two seconds using a reasonable sized computer.We get this either from the tracking or from GPS or some other reasonably accurate navigation system.

What we do is start off by assuming that that is actually where we are then we do a correlation check on it.Then we move one pixel to the left and do another correlation check on it and we go around and do another correlation check then we move two pixels over and so on.What we have now is a matrix of correlation coefficients.The largest number is the square that you are in. It is the one that has the highest correlation.So that is where you are.

Now in fact that says you are right in the center of that pixel but in fact if you do a center of gravity calculation on all the correlation coefficients you will find that you can find your actual location inside that pixel.You can find your accuracy to better than a pixel and that is important because if you look at these numbers they are not nearly as large as the radar.

Computations are shown in figure 76 I wont go into details as to what the computations are but what we are doing is a correlation and to do this on that amount of data requires a memory capacity of 0.3 gigabits.We are talking here of discs that will hold four gigabytes and that will hold the entire Seaway.So it doesn't seem like that much of a problem.We'd like to think around one gigabit of memory would be practical size that would hold the Seaway plus some and of course extra space could be used for electronic charts etc.We find that to do the correlation we need 1.64 million multiply and adds and since we are doing this in two seconds that means we need a 0.8 megaflop machine.Which is hardly pushing state of the art and in fact you can almost do it on a chip.It is not a big problem.

Comment: Dr.Austin:

I think you are over by about a factor of ten on the information you need to store and about a factor of ten over on the computation because the images can be run length encoded and otherwise compacted.There are a lot of zeros that don't need to be stored.Then in the computations there are various hierarchical schemes for reducing the number of computations that you have to do.You start with a coarse grid on a low resolution and you go to high resolution only when you've nearly got to the right place.I might also say that your center of gravity approach is not as good as a curve fitting approach.Essentially there are better algorithms for computing a higher resolution position than center of gravity.

Response: Mr.Ball:

I always love it when someone tells me that I am conservative in my estimates.When they tell me I need ten times as much I get worried.

Comment: Dr. Austin:

Well this works real time in a pretty modest computer it's not a matter of needing a Cray in the back of the ship.It's a pretty peanutsy computer.

Comment: Mr.Walker:

Are there not also some commercially available front ends like FFT devices?

Reply: Dr. Austin:

Yes,there are but the thing is you don't need them;they're unnecessary.Basically you can do it in software you don't need the hardware.Off the shelf Microvax will run rings around this problem;that's the sort of problem it is.The latest IBM AT will do the job no sweat and it costs $4000 or so.So although there are some interesting hardware devices such as the cheap one chip array processors,if you want to play with that sort of thing,they really are overkill for this problem.

Comment:Mr.Greenlay:

Is there not also a rotational problem that has to be addressed too.You've talked about the translation of the images but don't the images have to be rotated too?

Response: Dr. Austin:

Only if you don't believe your gyro.Presumably the gyro is going to be within a degree of the right heading.Other wise if you had to spin the image through the entire 360 degrees you could be calculating all day.You can expect the gyro you use to be within a quarter to a half degree of the gyro you used to record the images.

Comment:Mr.Cho:

You also have a finite length of time that your scanner has gone around.It's like it is taking a slow picture and your ship has advanced one pixel.From the time you start your scan to the time you finish it you have advanced one pixel.So your image is not quite going to match,the shoreline isn't quite going to fall where it started from.

Reply: Mr.Ball:

Good point.I guess we would have to use the over capacity to correct for these minor errors

Comment: Dr.Austin:

I'm quite surprised at the comments about gyros they're pretty reliable and accurate devices and you should be able to hold them to better than a degree,which is a hundred feet in a mile, which is pretty small per computation.I mean either the gyro is working or it isn't.

Comment: Mr. Raman:

We would easily get around the problem of image shift during a scan by only correlating particular sectors and any error within that sector would be negligible.

Comment: Mr.Ball:

While we didn't look at all the errors in the report subsequent thought indicated that half a degree error could add up particularly on a distant shore.It would probably be worthwhile to do angular checks of quarter or eighth degree shifts.And I'm glad that we have the excess computing capacity to do that.

Comment: Mr Ginsburg:

The same could be said of range difference or scale difference.

Reply:Dr.Austin:

I don't see why.The digitizer in the radar should be driven by a crystal which generally has extreme accuracy.If you pull the numbers off a PPI display from a traditional radar there is the possibility of having an error on the PPI but I think the digitally extracted images have the virtue that their range errors are extremely small compared to the analog PPI.

Return to presentation: Mr.Ball:

You've all seen this picture (fig.77) so I won't bore you with it except to say that now I am attacking this problem from a functional rather than a technological view because now I'm going to try to cost it.First a little bit of background on what all these boxes are.Costing,to put it mildly is preliminary.

We are talking about requiring a digitizer and a video processor.This is available.Furuno,for example have their own and other companies do their own digitizing so that doesn't seem a great problem.We are proposing six bit sampling but one possibility would be to use fewer bits.We are talking about a scan converter and that should not be difficult because a lot of companies make those.We need a high speed processor with memory.We must be careful about the word high speed because it means different things to different people but if an IBM AT can do it then possibly that gives you some idea of what high speed means.We require a compact laser disc memory.Those units are now on the market in the larger sizes. They are available in large quantities in the smaller sizes and we are talking $50 to $100 apiece for them.Current models in the large size run about $500 So we are not talking about a large outlay of money particularly when it will hold an awful lot of information.We need a video memory(high speed memory)and we are talking TV monitors,pretty good resolution, but since the computation is done all done in memory,not on the screen,what you see is the result.

Figure 78 shows how we costed it and if anyone asks me if we counted every chip I will say no.We took a look at what was on the market.We took a look at the technology.The number we came up with is quite pessimistic.It assumes that the costs on things like correlation chips won't drop or it assumes low quantities.If you gear up for higher quantities than 20 I don't see any problem with $30K at all.So our estimate was $60K to $90K as a good background number.It certainly isn't likely to exceed $90K which is a one off cost.

Non recurring costs(I've not included development costs because they are rolled up into the system costs) are due to the fact that someone has to go out and get the reference images.You can do it yourself by going out with your image correlation system and gather the data to prepare your own

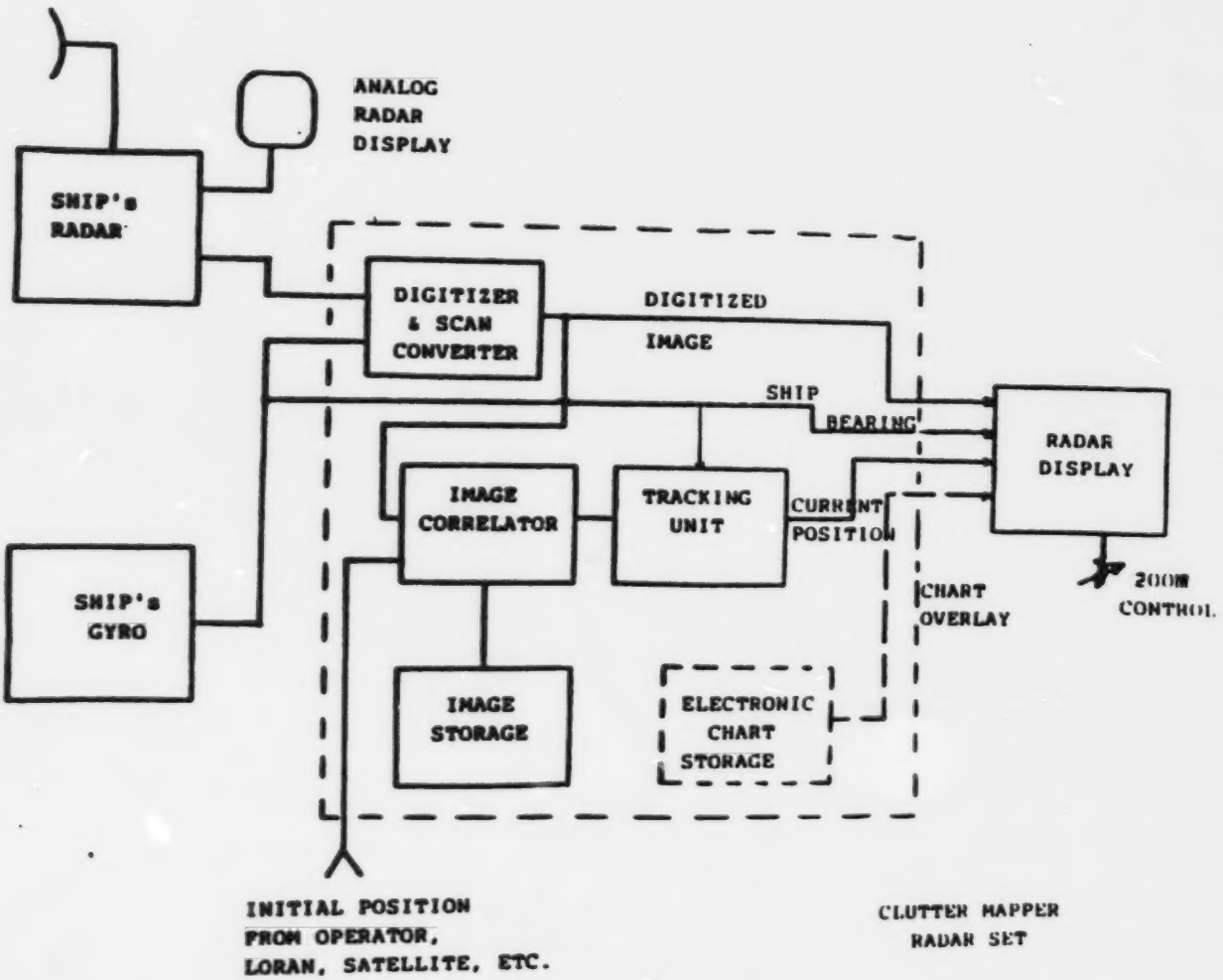


FIGURE 77: IMAGE CORRELATION RADAR

- COSTS
  - SYSTEM COST $60-90K IN QUANTITIES OF 20
  - NON-RECURRING COSTS:
    - REFERENCE IMAGE DATA GATHERING
      $0.5M - $1M
    - MODIFICATIONS TO EXISTING SOFTWARE
      $0.1M - $0.5M
  - FOR 20 SHIPS & 10 YEAR PAYBACK, AVERAGE ESTIMATED COST IS $60K - $90K PLUS $3K - $8K PER YEAR PER SHIP
- BENEFITS
  - ESTIMATED LOST TIME COSTS - $15K PER DAY
  - PROFIT LOSS UNKNOWN
- CONCLUSION
  - 7 DAY LAYOVER WOULD PAY FOR SYSTEM FOR 5 YEARS

FIGURE 78:ESTIMATED COST

data base or alternatively you can have a government agency do it and I understand that our own CHS are interested in doing that sort of thing.

So for a large fleet of 20 ships for 10 years would cost about $8K per year.Now I'm not saying these are precise figures but on a production run of 20 units this is the order of magnitude of costs.The benefits? Well we heard Capt.McDowall tell us that it costs $10K to $12K per day to run the ship and what the profit loss is I don't wish to say but the conclusion is that a seven day layover would pay for this system for five years.That sounds quite interesting to me.If I owned a ship I would look very closely at that number.

We would recommend that the next thing to do in this sort of job is to get out and demonstrate the concept.First we need to see if there is a market but if people are keen on the type of numbers I talked about then the next thing to do is demonstrate a system.Figure 79 shows our proposed action plan.The real operator interface is what we're after; will the captain use it or will he ignore it.

Our conclusion is that precise navigation is viable.Dr. Austin has gone out and done tests that show that even greater accuracy is possible.We feel that has been tested.Figure 80 shows our conclusions.The key issue is that the captain must have confidence in the operation.If he doesn't have confidence it won't go anywhere.We have to shake out some early bugs and maybe there are some improvements we can make ;some bells and whistles that we can put on for a minor cost.

I would like to deviate slightly to save a little time later on in our question period and play a couple of little games here.These may help to answer a question that hasn't been asked yet but may be.We have been using the term clutter mapper and image correlation interchangeably but there is a potential difference and we have to understand that there are two kinds of image correlation and we have been talking about one kind.

There is another,and it was alluded to by Mr.Lanziner and it is not non viable.I believe Dr.Austin has proven that it is usable.It is predicted not to have as good an accuracy(Mr.Lanziner suggested that in fact it did).What we are talking about here is a ship and a radar display and the object here is to find out where you are by using a new radar image and comparing it to an old radar image.Once you've finished that task then you drop the other thing on top of it (the electronic chart)and now you have the radar image matched up.We've gone through an intermediate step to get accuracy.We've said store the radar images.Other people have suggested using radar image correlation with map images.It doesn't need stored radar images.It is less accurate.How much less accurate?

I think it depends on targets that have some very specific characteristics;polarimetric reflectors,oil storage tanks etc.That will enhance your accuracy dramatically. Sharp targets that do not move can be used to enhance accuracy.What we are saying is that radar on radar is accurate:radar on maps is less accurate.

We feel that offshore,for requirements that are less onerous than channel navigation correlating to a map is quite adequate.I believe you did some tests on that as well.

Comment:Dr.Austin:

We didn't get it to much under about 50 meters though.

Continuation:Mr.Ball:

So that gives you a feeling we are talking about a two to one ratio in accuracy.

Comment:Dr.Austin:

Can I say why that is.Basically one radar picture looks one hell of a lot more like another radar picture than it looks like a map.So the correlation algorithm has a much better chance to be clever.If you compare a person with a person you've got a much better chance of getting it right than if you try to compare a person to a banana.

Continuation:Mr.Ball:

I thought I would end up with some questions for our little workshop and the questions that have been asked of me I've put up on the chart (fig 81).Will all these systems be rendered obsolete by GPS.That is a tough question because GPS is the be all and end all.Isn't it? I think, as Dr.Austin has earlier alluded to that the concepts of complementarity and redundancy are going to are going to force more than one system to survive.I want my radar on my ship so that I can see those other ships moving around even if I do have GPS signals coming down.

The radar system makes the electronic chart useable.

Is there a market for a precise navigation system? I certainly hope so.That is the reason why I'm here today.

CONCEPT DEMONSTRATION

- OBTAIN REFERENCE IMAGES FOR TYPICAL SECTION OF SEAWAY
- DEVELOP PROTOTYPE CLUTTER MAPPER SYSTEM
- INSTALL SYSTEM ON A SHIP
- OPERATE SYSTEM & MONITOR PERFORMANCE UNDER VARIOUS CONDITIONS
  - NORMAL CONDITIONS
  - HEAVY RAIN
  - SIMULATED HEAVY FOG
  - BUOYS REMOVED
  - REAL FOG

FIGURE 79:CONCEPT DEMONSTRATION

CONCLUSION

- PRECISE NAVIGATION IS VIABLE
  - REASONABLE COST
  - INDEPENDENT OF "OUTSIDE" AGENCIES
  - 6 SECOND FAILURE RESPONSE TIME
  - HEALTH STATUS CHECK EVERY TWO SECONDS
  - COMPATIBLE WITH REAL TIME RADAR
  - CONCEPT TESTED IN MARINE ENVIRONMENT
  - COMPATIBLE WITH ELECTRONIC CHART

- DEMONSTRATION ESSENTIAL
  - CAPTAIN MUST HAVE CONFIDENCE IN OPERATION
  - SHAKE-OUT EARLY "BUGS"
  - IDENTIFY NEEDED IMPROVEMENTS

FIGURE 80:CONCLUSION

NOW WHAT?

- WILL GPS MAKE ALL ALTERNATIVES OBSOLETE?
- IS THE TECHNIQUE COMPATIBLE WITH ELECTRONIC CHART CONCEPT?
- IS THERE A MARKET FOR A PRECISE NAVIGATION SYSTEM?

FIGURE 81:FUTURE CONSIDERATIONS

PANEL DISCUSSION

Moderator of Panel:
Mr.M.Avni:Transportation Development Center.

Opening Remarks:Mr.Avni:

Maybe before we open the floor to general discussion we should let radar experts among us to react to the most recent information presented here and I would suggest that we start with Dr.Haykin.Do you have any comments?

Comment:Dr.Haykin:

Mr. Chairman I have a number of signal processing questions because I have spent a large number of my years in signal processing.I am not going to address questions that relate to cost or reliability.I have to say that I really worry about correlation as a method.I say that for the following reasons:you have a reference that I would describe as a noisy reference or what we sometimes refer to as a random or stochastic reference.Why is it that I say that? Well,first of all you make a clutter map or whatever it is that you record.That recording is a function of all the following parameters:the radar frequency that you use ;the polarization that you use;the radar parameters in terms of pulse width,pulse repetition frequency and all the environmental effects that influence radar operation.So I say that is one important factor that will make your reference,so to speak,noisy.

Then there is another troublesome thing,basically the following: in digital audio systems,your compact discs,in a sense there you record your audio in digital format but it is well known that your disc suffers from the following problems;erasure,fingerprints and a variety of other factors and the net result is;that what you actually record, particularly when you produce this reference on a mass tape,because after all in this case every ship has to have its own reference;I would conjecture that any reference will have impulse like noise signals.Now that could be a real problem if you pick up interference from another ship which to the radar looks like another impulse and now you are correlating one impulse with another.

So basically what I am really saying is that;first,because of the variation in the radar parameters,the variation in environment,the variations in your recording system you have got a noisy reference.

It is a basic property of every correlator that the result you get is as good as your reference.I say. that before you jump in to discuss the reliability of the system there may be a problem in the reference itself.

Now,the point that was made with regard to the beam width variability.I would say that is fine as long as when I am collecting my reference I do my recording with the same

radar.In practice however,what you have to do is,go along the Seaway and make a recording that you make available to every user but the real problem is for another ships radar to correlate itself against a recording which was not made with the ships radar.So to say that I can now match the beam width of my radar and therefore improve its accuracy,that is a bit much.I think it needs clarification.

I have to worry about a long list of potential problems:we have identified.It is all very well to say that it is cheap to make.But if I have to contend with all those problems;they are basic and serious operational problems.Maybe we ought to go back to that list(figure 74 ed.).

Mr. Chairman,I guess I have to conclude that my reaction to the recommendations is that: they are what I would describe as the substitution of a political answer to a scientific problem and to me that really is unacceptable.

When you compare systems you have to compare them in scientific terms and to try to in effect say that I am forced into a particular solution,to me,that is not what I would call scientifically acceptable.I would rather have seen a recommendation that would have said:let us compare two or three systems.Whenever you evaluate any system you need a frame of reference.A frame of reference against which you can say that my system is as good as or as bad.To have no frame of reference you are just simply making assessments with no figures to back you up.

So I really worry about the conclusion to recommend one system and I say that not because our system was left out because that really doesn't worry me. What really worries me is the sense of the recommendation which I find really unacceptable.Especially all the points that had already been addressed in the report and some of the signal processing problems that I have tried to describe.

Now, before I finish,I think that Dan said: one of the limitations of our system was that it had no positive target identification.I really would like an explanation of that because it does not make sense to me.

Maybe in defense of our system,not that I'm suggesting that it is an ultimate solution because I'm always a believer in having more than one solution to any problem but if there is one thing that I can say about it is that it follows the cardinal design rule KISS, keep it simple,stupid.I really think that our system has one merit in that it is simple.

Reply: Mr.Ball:

What we meant by saying that the polarimetric reflectors had no positive identification was that in comparison to a microwave transponder which sends out an identification code there is no way you can tell the reflection of one reflector from the other.

Comment:Dr.Haykin:

All you have to do is position these reflectors in a unique way so that as I go from one location to the next I will have built in a "code" in the way I position the reflector.So to say that there is no positive target identification, I think that is invalid.

Reply:Mr.Ball

That would not be a disadvantage if you had the location of all the reflectors in memory and the locations were not critical.What we were worried about were cross polarized targets nearby,things like large vertical rock surfaces pulling the radar off target.If you know exactly where they are then you have no problem and of course if you have identification then you have no problem.I think however,that I agree with your conclusion that it is such a minor disadvantage that we shouldn't have bothered listing it.

Comment:Dr.Austin:

The concern about heavy rain seems to me to be addressable by going to an S band radar.Most people who work in offshore areas where there is very heavy rain usually operate an S band radar as well and it clearly has a superior performance in rain and I think in any of the systems we're talking about that would be what you would have to do if rain were a real problem.It's unfortunate that the angular resolution is generally worse but possibly you could live with that.Certainly in Newfoundland for example very heavy rain exists so most of those drilling platforms believe their S band before they believe their X band radars,certainly during the rainy season.So that's a possibility.

I agree that the weakest aspect of the work that I presented is the difficulty that when you go from one ship to another you will get differences in the image between what you get from the radar on one ship and the radar on another ship.I suspect that the height of the antenna above the water would be just as significant in changing the imagery of the clutter as would be the beam width,which I don't believe will make a great deal of difference except at the finest positional level.But,I think that the height might be quite serious in the sense that as you go higher up you get more clutter.

However, we have had a lot of experience in using these cross correlation algorithms in a variety of much messier targets than radar images of clutter.We use it to track rain showers to make short range weather forecasts,which is where we started in this.There are drastic differences between one time and the next when you look at those echoes.They are amorphous blobs that change their characteristics

drastically.The correlation algorithms are surprisingly robust.

One concern I had for instance was: what happens when a ship goes by? You have got a particular array of ships on the reference image and another array of ships,presumably unrelated with the first lot,on the real time image and you might think that it gets you into trouble.When you look at it however it is a minor problem and I think it covers the issue of what happens if there is a noise spike on the reference image.You have got to bear in mind that a quite high percentage of the screen area you are looking at is covered with echo.Therefore you are doing a huge number of calculations.There are a large number locations on this image and there are a large number of locations on that image.The fact that it is drastically different at a few points in there is going to make very little difference.So you can certainly have ships in different places and it doesn't immediately navigate you off to match the ships.There is no risk of that.These targets are by and large tiny compared with shorelines.So we know for sure that the ships per se are not a problem and therefore I suspect individual noise spikes on the stored imagery will not be a problem either.

The question of variable shorelines with tides worries me somewhat so I'm conceding the two major problems are going from one ship to another particularly with respect to height and ill defined shorelines that vary drastically either with tide or time of year.However,I should like to point out that a lot of those tidal shorelines and there are some very flat areas of the St.Lawrence Seaway where there is not much to see along the shoreline,always have a whole bunch of clutter in the form of farms and barns and lamp posts and all sorts of other trash.

In the imagery I showed earlier there is a very straight piece of coastline and I thought there was going to be a major problem.Because if the coastline is dead straight with no bumps and wiggles on it I would presumably be able to correlate the perpendicular,the cross track distance to the shoreline,but I thought that I would have real trouble positioning along the shoreline.It turned out that we did not and the reason is that there is all sorts of stuff there that is not on the map.There are trees and rocks and farms and all that stuff and it produces a lot of texture in the images.Which isn't apparent when you look at it on an ordinary radar PPI that is just thresholded off and on but when you look at this thing in glorious technicolor there is an enormous amount of texture which really does survive from year to year.

If you were dependent on any one of these things I think you would be in trouble.For example a circular building is trouble because as you move by the reflection point moves around the building.So if you have a circular oil tank 100 meters in diameter clearly the reflection point from that one target stands to move by 100 meters.So this

would be bad news.However, what the global cross correlation algorithm succeeds in doing is to produce a global average off all the stuff that's there.I argue that with the images we've produced thus far(and I'm quite willing to believe that what we want to do is more extensive sea trials in perhaps less attractive environments than Halifax harbor)that it appears to work well.

It would be an entirely worthwhile experiment to do some of these things down portions of the Seaway where the coastlines may be a lot less attractive.We really won't know the answer to that until we try it.

I am somewhat concerned about antenna height on ships and the effect it has.On the other hand it would rather easy to put three radars on a ship,on a tower at different heights,and you say how high your radar is above the ground and you get the appropriate set of maps.That may solve the problem.I think the beam width one is less of a problem it's not likely that you'd want to record images with three beam widths but if one were sure that X band were all that you were going to get into maybe even that,s possible.

My feeling is that the prototype system exists.Instead of analyzing it as a theoretical problem it's much safer to put it on a ship and do it.We'll get egg on our faces a lot quicker if we do that than if we do paper studies.So I'm all in favor of doing experimental work.So if we show that this system is incapable of working under certain circumstances we then have to answer the question whether these circumstances occur often enough to constitute a real problem or whether it occurs in those areas where the precise navigation requirement is less severe.I don't think this is a closed issue.I'm anxious to do some more experiments.I believe that the results we've got with the correlator so far give one reason to be hopeful.I think the best thing to do is to go and do it.

Comment:Mr.Avni:

Would you care to add further to this,Mr.Lanziner?

Reply: Mr.Lanziner:

From our stand point we are very concerned about the cost and immediate availability of a system that is workable and usable and I have to say about Dr.Austin's comments; that his concept is viable and should be pursued but what we are looking for is a system that exists now that we can get going on almost immediately.

Question: Capt.Fisher:

I have a question for Mr. Ball or Dr. Austin concerning the making of the master recording;fixing the reference every half mile or mile,how do you propose that be done?

Reply:Dr. Austin:

I think you'd have to deploy some sort of navigation device like the mini-ranger system that the CHS have.They have a portable system that they deploy on the Seaway when they put the buoys in.It would be better if we could get something better than that but for the time being that would be sufficient.

Comment: Capt.Fisher:

So the accuracy of your system would be the accuracy of the datum aid.

Reply :Dr. Austin:

Quite so! One could obviously deploy laser type devices over particular parts of the Seaway if you wanted to do a more precise scientific type of experiment but I think if you wanted to be realistic and wanted to do the whole Seaway you would need something that could be installed rapidly then moved further downstream otherwise the job would take rather a long time.My impression is that the Hydrographic service are rather keen to try this.I think they see the idea of having "radar charts" as they call them in parallel with the regular charts as being a good one.The British Admiralty for example have been producing purple overprints on some of their charts showing radar prominent features for quite a while.

Question:Mr.Bertrand:

I'd like to address a question to Mr. Ball.In the context of the study that Canadian Astronautics performed they were indeed put into an awkward position and they were given certain criteria to make their selection and cost was one of them but with respect to the polarimetric reflector option,just how heavily was the cost factored in i.e.the cost of towers, land acquisition,etc.How heavily did cost weigh in the life cycle analysis or rationalization leading to a selection.

Reply:Mr. Ball:

I guess I can only answer your question one way that is the short list met all requirements and had no obvious deficiencies we were not able to see the significant merit of one over the other and cost became the discriminant.I guess the only way to really finalize a choice would be to go out and test the candidates one against the other.We only had $50,000 of engineering time to look at the possibilities and that ran out before we could really put any thing to the test.Given the criteria we had, the clutter map came out the best.The only one that I am still not sure

of is GPS since it shows such potential but also has so many unknowns associated with it.I guess at the bottom line it came down to cost.

Comment:Dr.Haykin:

I have what I think is a fundamental question.To go back to my original point and try to illustrate it in a way that all of us can understand it.Supposing I wanted to establish secure communication between point A and point B,the way that it is done today is to use what is called spread spectrum communication which is really a correlator.The interesting thing is that you do not use amplitude changes to correlate you use instead a phase coded correlator.The reason for this is simply the fact that amplitude as a discriminant is not as reliable as phase.To illustrate my point again;when you listen to radio which is it that you consider more reliable: AM or FM ? The answer to that is obvious the FM radio is considered more reliable because AM relies on amplitude variation and we come back to the the simple fact that amplitude is not a reliable discriminant.So in sense in your clutter map or whatever you are going to call it: point one your reference signal is noisy,point two it relies on amplitude which from a signal processing point of view is not reliable.You only have to look again at spread spectrum communication where you do phase correlation or at AM vs.FM radio and the answer is obvious to you.I say there is a flaw there that is fundamental to a correlation that depends on amplitude and I don't think that question that I raised earlier has really been addressed.

Comment: Mr. Williams:

My worry is that all navigation systems are expressed in statistical terms that is standard deviations of one sigma or two sigma.I've always been concerned about the last one or two percent and perhaps this is where I have trouble with correlation.What worries me is that people say "90% of the time I can give you 10 meter accuracy" and that's fine for going to find little fishes and patches of rain and all that kind of stuff but it's the last one percent that always concerns me and I'm not sure there are any answers and I'm not sure I'm helping you at all but if I were a user of anything like that I would be very concerned about that last one percent in fact I would be so concerned the only way to allay my concern would be to actually measure it.

Reply: Dr. Austin:

Well I showed you some measurements they didn't show wild values going in and out of Halifax harbor that's all I can say about it.There were no 200 meter errors suddenly appearing out of nowhere.

Comment: Mr.Williams:

I'm talking about a ship here and it's going up the Seaway every single day of the year,and how many ships are going up there.You've got to test it and you've got to prove it at the 99.99 or better confidence level before you will sell it to any one.

Reply: Dr.Austin:

But, that's why you've got to integrate the GPS with whatever other navigation device you've got.Then you've got belts and braces;if the two don't agree then you stop or whatever whatever is the safest thing to do.

Comment: Mr. Williams:

But they do agree.

Reply: Dr.Austin:

But the thing will scream at you if they don't you can't expect it to do more than that for you.You've got to decide what to do if they disagree.It seems to me the solution is to have a warning and health check,that sort of stuff.

Comment: Mr.Walker:

I'd like to make a comment.I don't think anyone has pointed out one of the advantages of Dr. Haykin's device. Intrinsic in setting the reflectors up they are ground truthed.You must survey the reflectors in and you can use the highest grade of surveying that you can bring to bear on the problem.In other words you have to have these things to a few centimeters on whatever geodetic reference you want to use.To put the reflectors in they must be surveyed in.From that point on everything else concerned with Dr.Haykin's system has an error budget that is the same as any radar based system.From this,it seems to me that we have at least a chance,over a small truthed section to look at the comparative virtues of the two systems.We do know that the reflectors are ground truthed.We can find out how well the correlator will truth in because we can use the reflectors as a survey system.We will probably have to do some pretty heavy signal processing on the leading edge of that radar pulse nevertheless,the reflectors themselves in a proper constellation(and as a navigator I would never use a single reflector,I would always go range/range before range azimuth and I would never go azimuth/azimuth)are a survey system.

It seems to me then in terms of cost we are not talking 314 reflectors along the length of the Seaway but 5 to 20 along a small section and we can prove things.Clearly if we continue to argue theoretical points no one will believe us

but if we go out and actually do the trials we will be able to find out what indeed,the truth is.What are the relative costs.Do we really need very complex constellations to achieve proper identification or could one truthing reflector every 20 miles upgrade a correlation system.

Reply: Mr.Ball:

I think the real question in the last discussion is what is the reliability of the system.I think we tried to address this question with the two second test.Every two seconds the system checks itself.Our approach is that the system is reasonably intelligent and can run this health test every two seconds.

There is one point I didn't mention.When you do a correlation matrix the numbers themselves have meaning in other words the higher the correlation the more confidence you have;the lower the numbers the lower the confidence.What we have happening,say in a rainstorm,is that you see all the numbers dropping across the board and that sort of number can be displayed to the operator as a confidence number.I think that should apply to all systems whether GPS or any system.Some sort of periodic health check is absolutely essential.

Comment: Mr.Lanziner:

I should like to say that I believe that what the McMaster concept is doing is in fact providing self check all the time.You are dealing with concrete reflectors,with positive returns.The system I mentioned earlier works in very much the same way.The way this system works is by azimuth gating in sectors and by range gating.Once it is locked on in an area where you know you are it will constantly look for other reflectors.If it has problems seeing its original reflectors or if it misses one it will trigger an alarm.If it still sees 4 or 5 or 3 or whatever you have set as the minimum it will still provide a good position.But in fact every time it updates a position with the required number it will confirm that the position is sound.It would be very unusual to find other reflectors at exactly the same right range and right azimuth where the chosen natural reflectors are.This is the heart of that system we did not need to use rotated polarization reflectors and we did not lose position once.We tried all kinds of fast turns and stops and running near the edge and we couldn't fool the system.

Another thing,although normally in radar you don't use the azimuth,because you have relatively wide beam pattern,because you know where these reflectors are you can get your ships azimuth to a far greater accuracy than a ships gyro will ever give you.This concept is all implemented in software.The identification is accomplished

by knowing where the natural reflectors are.The secret is that you use a fairly large number of reflectors and if necessary you could use a passive reflector every so often to check.

Question:Mr.Ball :

Why do you have to use a passive radar reflector as ground truth? Why can't you just use some object that you have placed there?

Reply:Mr.Lanziner:

I'm not sure whether you have to or not but what I'm saying is that you should use something that you have actually put there.

Comment:Dr.Austin:

I'm sorry but with a building there is no way you are going to position yourself to 2 meters.Buildings are bigger than two meters and the reflection point is going to move a hell of a lot more than 2 meters as you go around it.

Reply :Mr.Lanziner:

I haven't seen the system to 2 meters but all the time I was on board we were within 15 feet.What they actually allowed for was a coding that identified a building as such and you could key in the angle of the walls and the length of the walls and the system would use that as it looked for the reflector.I said about a year ago that such a system could not work accurately without a tremendous amount of sophistication.Well I think the system I saw had that sophistication due to processing techniques developed in the last few years.

Comment:Dr.Austin:

I'm sure it gets its accuracy out of the fact that it's looking at a lot of targets at the same time.That is why the cross correlation method looks at all the targets.So the logical extension of that is to use every dimension in your X Y domain as your target.

Reply : Mr.Lanziner:

What I'm talking about here is a very positive method,we're not worried about tides,we're not worried about ice on shore.When we see those targets we know exactly what we're looking at.

Comment: Dr.Austin:

That's what scares me because the traditional method whenever you bring your ship up to land is for the captain to say,"that's head land or that's point or whatever" and he looks it up on the map and if he gets it wrong then he could be miles out.That's a real risk.

Reply:Mr.Lanziner:

Well it didn't do that.I'm sure that the possibility might exist but when we tested the system it did not fail.It was not very fancy in hardware and that is a concern for us since the cost drives our sales.

In our discussion here there have been several concerns raised about the correlation concept and only one,the identification problem,with the McMaster concept,which is not a problem from what I have observed.The other problem with the McMaster concept is that you need a special antenna.The radar we used on our trials was less than $5000. It is a commercially available radar.In the worst case you have to design the special antenna but it's not a lot of hardware.where again,with the correlation method you have to move a lot of data around,a massive amount of data compared to looking at just one sector.

We are looking at getting this system to Vancouver for a couple of weeks to give it a thorough test program.As I said we only had a few hours to look at it and we'd like to test it more thoroughly.

Question:Mr.Stiles:

Mr. Lanziner's description of the programming of that system brings to mind the experiences we had with the original ACCI system.It was programmed in exactly the same way,range and azimuth windows,and of course reflectors were strategically located and surveyed in,to within 2 centimeters.It was quite a job for the Hydrographic Survey,but they carried it out the program as laid down.This system you are describing,and if you are going to test it in Vancouver you may well find out,will have,as did the ACCI system,as it's greatest weakness,the reflector.In our case we were very much buoyed up with what was going on.We knew the system had strengths and lesser strengths but this brings up Dr.Haykins concept of twist reflector.On two occasions during our test of the ACCI system in the Prescott area over the period of a summer the reflectors failed.

The reflectors were surveyed in during the late part of the Spring.Then we had our first test.Then we had problems and we had to go back to the drawing board.We came back to test it in August and September and the whole thing fell apart.By this time we had all the key people we needed to test the system.It fell apart for several reasons.One of them was that on one reflector a self unloader had appeared

and was in close proximity,right in the window of that reflector and near another another reflector upstream someone had built a cabana with great straight metal sheeting sides just off to the side of it.Of course the whole thing fell apart.This was why we went into the development with McMaster because we had proof positive that we needed a reflector that was independent of amplitude.

Comment: Mr.Ellwood:

I have one comment or if you would a question that perhaps belongs after coffee during the discussion of priorities.It relates however partly to the function of this session which has culminated in the CAL study as to which of the available systems are best,to evaluate the systems technically.Unfortunately,to my mind,there has not been any evaluation as to how well our research and development funds for Transport Canada have been spent in pursuing this whole area.

We have a certain role in the department to promote systems that are universal in nature,with broad safety and public benefit in mind .Systems which are easily accessible and will fall within our mandate to provide.The focus of all the work we have been talking about so far seems to come back to user specific,site specific initiatives not necessarily related to universal navigation standards.I think the gentleman from Algoma indicated right off the top this morning that the bottom has fallen right out of the market.The original market for the system was in the Seaway and the other places where there are markets for these systems seem to be provided for by technologies other than those we have been investigating.It seems to me we have spent a fair bit of money and the market doesn't seem to be there.I guess my question is:are we doing the right thing? Are there spinoffs of the work which might be beneficial?

Reply:Dr.Haykin:

I feel that as far as the scientific part of this work is concerned I have said my piece.But,now that you have opened this question I have to give everyone the benefit of some of my thoughts.I have to say that in many ways I am upset.Perhaps upset is too strong a word.Perhaps worried or discouraged might be more appropriate.Some three or four years ago we met in the steering committee and questions were raised about the polarimetric radar.GPS was mentioned and here we are today four years later still worried about GPS.

I guess I can only describe it as being: **paralysis by analysis.**

I say we can't afford to do this anymore.When I look at what is going on in the United States today and then come back to Canada I find it worrisome.It is really so worrisome

that unless we put our house in order we will fall behind so badly that it will take a miracle to catch up.

I can only see a few cures for this.First let's have a little bit of confidence in ourselves.We don't always have to be second rate.Just because an idea is developed in Canada does not mean that it is an unworkable solution.Let's take a few risks;whether it's this system,whether it's a correlator system,whether it's both or whether it's another,lets try it.I think time is running out and I think that unless we do something before too long someone else is going to cash in on it.

We in the universities have a habit of writing papers: that is what we are judged on.Those papers are published in journals and see a large,international,audience.The longer we keep ourselves from decision making the sooner someone else will pick up our ideas.I would venture to say that four years from now we will meet again in this room and we will still be worried about GPS and I say we can't afford it.

Comment : Mr.Rudback:

I should like to give a partial answer Mr.Ellwood's question as to whether we should be doing anything at all.I would tend to side with Dr.Haykin,if we don't do anything the world will pass us by.We have already seen spinoffs from the McMaster work in the development of a device that will have many applications across the spectrum of navigation requirements.

If we expect research and development to show results next year we are in the wrong game.Mr. Ellwood has raised a legitimate question but I think the time to address it will be when we discuss R&D priorities.We said in the opening remarks that part of the objective of today is to look at what we have done:to take stock of the situation and then look at what needs to be done.Of course this must take cognizance of Transport Canada's "customers"the marine industry.I suggest then we defer further discussion of this until after the coffee break.

R&D PRIORITIES: DISCUSSION

Call to order:Chairman Mr. Avni:

Let us continue,I believe professor Austin wishes to make a comment.

Comment: Dr.Austin:

Yes I wanted to address the last comment we had just before coffee that there was a feeling that Transport may not have well spent its thousands of dollars of research funds in terms of what it got.I wish to remark that from our point of view you have no reason to worry,because you haven't given us thousands of dollars and therefore the messy situation we are in is not at all due to your misspent funds.We have received about $30,000 from CHS and Transport combined which means that you are into it for about $15,000. The sum of money is small and was only used to take equipment developed through an NSERC grant into the field to see what would happen.

It seems to me that what professor Haykin said just before the break is exactly correct,that Canada suffers from a chronic lack of confidence and that in a sense it doesn't matter what we do as long as we do something.What we mustn't do is keep talking about it for the next twenty years while Decca and Plessy and RCA and Litton and any other offshore company shows us how to do it and then we all rush out and buy it because it's now American technology and it must be good.How we can get away from this I really don't know but we need to.

Comment: Mr.Rudback:

Perhaps this is a good introduction to the next portion of this session,the argument over priorities.Up until now we have looked at various technical approaches to solving the marine precision navigation problem.The specific application that was used as a case study was navigating in the Seaway,principally because we were asked to and the Coast Guard and Transport Canada agreed that this was the first step.In the process we have looked at all the technologies that can be applied to the problem and one of the obvious things that comes out is that the Seaway is not the only application.

There is a requirement for this kind of system in ports,in confined waters and channels and in the Arctic where conventional navigation aids do not exist.So there are other applications.In fact looking at what has happened over the last five or six years I think the Seaway might not be the best first application.The capacity crunch that was forecast then has not arrived.In fact times are down as was described this morning and the industry is in survival mode.Furthermore,in a technical sense the Seaway with 600

foot channels and vessels passing is probably the most difficult challenge and the last place you might want to try this sort of thing.Perhaps some of the other applications might be more appropriate for first application and,in fact we are seeing this happen.

In a technical sense there seems to be certain themes coming out of these sessions.The question of integration of different technologies and putting them into a display,the question of the display in particular in which we have developed excellence,is essential to the development of any navigation system.To agree with professor Haykin,if we sit back nothing will happen.

The other theme that comes out is that we need redundancy and backup and complementarity and a certain degree of flexibility for what will prove out and what will not prove out.There is no doubt about GPS eventually being available there is considerable doubt as to when and what accuracies will be made available and what the reliability or system integrity will be.It will be there and any system developed will have to take advantage of it.From a private sector point of view one has to be making systems in terms of cash flow.In other words there has to be some sort of market now,so one has to consider what sort of technology is available now and of course the market is down right now.

In terms of the common themes that are coming out,the electronic chart is an important one.The technology is available,although not available for all waters it can be made available very readily and we see that the electronic chart is apart of the navigation system that will be serving us in the future.

I would like to think that we could simply proceed and fund this type of activity because it is good technology and will have applications in the future.Unfortunately,we are in a period of constraint and Transport Canada is going through a reduction in budget to meet cost reduction targets.So the particular things that are important to Transport Canada at this time are those that can save us money.So any research proposed will have to stand up to rigorous cost benefit analysis and show very positive return on investment before it gets funding.However,I'm generally in the position of having to defend R&D and R&D budgets and if the first thing you do is sit down and think of the reason why it won't work and how much it's going to cost,then nothing is going to happen.

I would suggest that when we discuss R&D priorities let's think in technical terms and in relationship to the things that were discussed today,just what can be done,what should be done from an industry point of view and user point of view.In due course there is no question that the questions of market and cost benefit will weed out some of the things that are not practical.However some of the things that we might wish to consider are:the strengths and weaknesses of the various technologies that have been

discussed,some of the potential applications,and the technological thrusts that are likely to produce the best payoffs.

In our discussions we might want to look at the role of the private sector in furthering development.I am thinking particularly here of companies that are in the business of selling navigation systems.At a certain point in time the government through Transport Canada has provided seed money to get things going,to bring technology up to a certain state of development.As you all know government is slow,that is a fact of life and at some point in time if a technology is going to take off in a private sector economy then the private sector will have to seize ideas and carry them through.I believe the private sector is very good at that.

When it comes to government support that is needed there are various sources in addition to Transport Canada for that:DRIE,CHS,DSS etc.In terms of getting things moving,if some of this technology is emergent and breaking through right now,becoming a practical reality,perhaps some demonstrations in the private sector are what is needed to carry it on.

I don't want to dominate the discussion,instead I would like to solicit your points of view on where we might go from here.

Comment: Mr.Kendrick:

I very much agree with trying to bring the private sector into any initiatives that are taken but to be frank,the biggest up front spender on navigation directly in Canada seems to be the Canadian government in the aids to waterways branch of Transport Canada and the Hydrographic service.Has any of the work that has been carried out on precise navigation sparked their interest and if so what further action do they intend to take on it.One of German and Milne's traditional sources of income has been designing buoy tenders and hydrographic vessels,certainly for the last 60 years so this may be an unwise issue for me to raise,but,looking at the ways some of these vessels are used and how little some of these are used there are major potential savings to be realized if the Canadian government does encourage,by it's own acquisition of precise navigation systems private industry to do the same.

Reply:Mr.Rudback:

I have an Assistant Deputy Minister who continually reminds me that these traditional aids to navigation,which have not changed significantly over a few hundred years represent a very costly process putting them in and taking them out on a yearly basis.I turn then to the mariners and naval architects and ask why can't you get rid of these? I have not quite succeeded in doing this yet.Part of the problem is that you probably will need duplication and

redundancy for a long period of time until you can build up confidence and the potential payoffs are a long way off.But,I think you raise a very good point in the sense that it is long term futuristic research and that is one of the reasons that Transport Canada has invested in it.

Comment:Mr.Ginsburg:

We have one example now where we are doing experiments with the Offshore Systems equipment such as has been described and our region has proven that there is indeed a saving in ship time in the servicing of buoys and their replacement in winter.There is something happening there.Where there is a payoff I don't think that it will take very long for Transport to invest in it.

Comment:Mr.Kendrick:

I am very glad to hear that because as has been pointed out several times today from both sides of the table,the marine industry is a very conservative industry.Something we often hear from people we try to sell ideas to,particularly if the government has partially funded these ideas,is if it's such a good idea and the government has payed for it,why isn't the government using it?

Comment:Mr.Ellwood:

Some of the additional efforts that are going on in the Coast Guard and marine areas include working towards using differential GPS for navaid positioning.The electronic chart area, working with the Hydrographic Services,is also an area of central concern,recognizing that,in the future that charts will be digital and that their associated displays will be on most ships.Another area that is fairly standard though not always recognized in public is the fact that in the longer term something has to be done to examine the pilotage situation.Electronic chart and GPS present a very high yield in terms of a solution to the problem of compulsory pilotage.In this context Ted's comment about the Seaway not being the best or safest place for testing a precision navigation system might also reflect on the pilotage problem.

Comment:Mr. Walker:

I presume that every one around this table knows who is the highest paid public servant in Transport Canada? He is a pilot on the Fraser river.Counting overtime,he earns more annually than the Deputy Minister.So pilotage is a very important issue if we are talking about costs.

Comment:Mr.Stiles:

I get the impression,rightly or wrongly,and this dates back to six or seven years ago,that the Coast Guard was never really in favor of this precise integrated navigation system.At the time it was better known as PRANS.We had no funding through them except finally through the TDC.But,the Coast Guard always seemed to be at a distance and we could never get from them where were they going? What was their long range plan? So that we never knew whether they were secretly watching us and were all their eggs in one basket.Certainly we knew it wasn't in PRANS and I get today that really I suspect that their effort is really not in PRANS.I get that their effort is really in GPS and differential GPS as described by Mr.Ellwood.I don't think that it has a very great export possibility as other possibilities that we have discussed here.

Reply:Mr.Rudback:

First let us make it clear that Coast Guard and TDC are all part of Transport Canada.We work hand in hand.Perhaps I can address the other question asked previously:if we invest in the technology why don't we buy it? Coast Guard has an operational role and TDC has a longer range view and I think it is important that the operating people have a somewhat hands off stance from development.They have to choose the best possible system at the lowest possible cost to enable them to meet their operational role.They would compromise their position if they had to buy every system that they examined.In this particular case they requested that the TDC be involved and then they kept in touch with what was going on.I guess it is true to a certain extent that the GPS solution appears ideal,at least in the long term,but the private sector has to be delivering right now.Mr. Ginsburg has mentioned that the Coast Guard is investing in this type of technology right now and we are the first customer for it in Canada.

Comment:Mr.Ellwood:

I should like to add as well that there are two factors. One is levels of service issues,the government spends a certain amount of money and provides you with a certain level of service.Investing in a new system implies a greater level of service which once provided in one location must be provided in all locations leading to increased expenditures.From the Coast Guard perspective as opposed to the broader research and development perspective there has been a high level of caution about being trapped in being forced to make additional expenditures when the existing system is deemed,at least in its operating context,to be safe.

Another aspect is that when you pursue an area of research you get into spinoffs,and I think professor Haykin has got some other innovations in the area of marine radar.I think the world,navigator's would benefit immensely from improved marine radars and possibly such marine radars will obsolete the need for such a system as PRANS.It may be imprudent to rush into such a short term investment.When there is already an indication that there are other ways of doing this on the horizon.Exportability of PRANS is a dubious venture in my opinion.

Question: Mr.Rudback:

Does any one wish to comment on the exportability of some of the things we have been discussing?

Comment:Mr.Lanziner:

It's interesting since it's typically Canadian that we don't believe in our own capabilities until we bring it in from the outside.recently we bid on a large sized contract,close to a million dollars,with the US Navy.We were bidding against people like Honeywell and large US companies.When we received the contract,then we started getting a whole bunch of attention from our Canadian people saying you must be good if you've got a contract with the US Navy.On the one hand it makes a lot of sense but it's rather a shame that we have to prove the technology outside the country before we accept it inside.A similar thing is happening within the province.We have been trying to sell to BC ferries for the last two years and we have systems with Marine Atlantic and Ontario Northland who have taken the step in recognizing that this is an aid of definite value to them and yet we still have not convinced BC ferries.

When we do export systems the whole response changes,not only within Canada but elsewhere as well.At the same time we are organizing our own marketing efforts and refining specific markets in the US and other countries.

Comment:Mr. Ball:

If I can comment once more from CAL's point of view.CAL is in a situation where we have a catch 22.To sell anything in Canada the Canadian government says prove it by selling to an overseas country or government.The first thing the overseas government says to us is;has your government bought it and we have to say no we are waiting for you to buy it.One of our products was very successful overseas to the point of requiring 15 employees.Finally the Canadian government came to us and said yes it's good enough,guess we'll buy one.From a marketing aspect overseas I'm sure you'll realize it's twice as hard from that point of view.So if you're OK with your own government that gives

confidence.So if you ask us what is the export market potential I would say it's great but if you buy it it's even better.

Comment:Mr.Walker:

I'd like to make a comment on exporting navigation systems in general and,as a navigator I think I can speak from a reasonable amount of knowledge in this game.We are always tending around this table to be blinded by the GPS and its capabilities.What we forget is that in terms of an export market there are nations in this world that will flat not only refuse GPS but will do everything they can to avoid it.

Some of these nations are quite paranoid;I will give an example.When deHavilland went to Chile to sell Dash-7's as patrol aircraft,they were offering Canadian Marconi Omega receivers as the main navigation equipment,the Chilean Admiral told them that he would never use a navigation system in his aircraft that was controlled by other nations.Now anyone who knows the Omega system knows that it is a completely international system.In a sense it is held hostage by the nations that provide the service:Australia,Argentina,Japan,LaReunion(France),Norway,-Liberia and the United States.No one is going to shut down an Omega transmitter without causing a real ruckus in the international arena.

So this little example illustrates that there is a market out there for Canadian systems.To sell to nations that don't want to infringe on their sovereignty.Saudi Arabia for example has just installed Loran-C for their domestic use as has the Peoples Republic of China for the specific purpose of enhancing their sovereign interest which is best met by a system that they themselves control.

A PRANS type system would be perfect for the Rhine(if anything's still living there after the toxic chemical spill).If you look at all the nations that border on the Rhine you will quickly realize that at least three of them will have nothing to do with GPS for sound internal political reasons.Following this reasoning then,without specifying which particular navigation system,I feel there is a good market for a Canadian developed navigation system if we look around the world to find our particular niche in that game.It is not GPS or differential GPS.It is another system that can be handed turnkey to somebody else.Let them operate it at home.

Comment:Mr.Lanziner:

Another thing I want to say about GPS,I'm still a little puzzled about all the hoopla about it being the ultimate answer.At this time the dynamic accuracy of differential GPS has not been demonstrated.We are speculating.We are talking about differential GPS in the non

dynamic mode.There have been all kinds of experiments with ordinary GPS and there are all kinds of non coded concepts in the works but a system does not exist at this time.Sure GPS can be the answer if we wait long enough;five years ten years.somebody will come up with a differential system to make it work with the required accuracy.Right now there is no such system.

Comment:Mr.Bertrand:

In that context I'd like to add something as a non expert in navigation systems.It makes a lot of sense to do this thought experiment;If GPS was turned on tonight,tomorrow you can all access it;how well could it be integrated into the marine operations of the Seaway or Arctic.Before any such system,irrespective of precision,can be incorporated into any operation and used with degrees of confidence,to break the natural resistance,to use it,to rely on it.I guess what makes sense to me,before all of that takes place,irrespective of the introduction date,there has to be a transition by which precise navigation technology;the display,understanding,the incorporation of these fast moving technologies such as; storage capability, display capability,integration of position,pattern recognition,artificial intelligence etc.I sense that we cannot wait for this to happen.Without the proper transition during the interim playing with it getting used to it at reasonable cost we are not going to be able to make effective use of it in a timely fashion and derive benefit from it anyway.Unless in a small way we move in a given direction and recognize the inevitable.One day it will be there.

I think we are facing a bit of a dichotomy here.We have to keep something on.We may have some hard choices to make but the waiting game will benefit no one except maybe some very short views that it will look good on you this year to report that you have not spent anything.In fact you will not have gone forward you will have gone backward.

Comment:Mr.Lanziner:

Besides one more thing,GPS to us is just another input into an overall integrated concept.GPS together with radar,GPS with Transit,GPS with Loran-C will produce a much better position and we can put it together now we can demonstrate it now.So it's just another input in the overall package giving you better redundancy and better accuracy.

Comment:Capt.Fisher:

In answer to at least part of this question no one mentioned another river,the Mississippi,which Paul Cojeen has to deal with.They aren't waiting for GPS and their requirement is similar to ours.

The other point is;we were saying a market we only have to look at Canada.Algoma steamships have one ship that runs to the Magdalen Islands to pick up salt.They make about two to three trips a year.They have to install a navigation system,a company from Halifax puts it in and takes it out and this thing costs them $27,000 a shot.We know that Dome put one in at McKinley Bay and I will directly ask Dave Williams;why have you put one in at Port Au Basques why haven't you waited for GPS.

You have two ships making quite a few trips a day.The system you put in and I'm going to talk about the shore based component.The system you put in to cover a very small area like Port Au Basques is pretty expensive,maybe you'd like to tell us later approximately what it is.We know or at least I accept that the passive radar reflector can be viewed far enough so that we can be reasonably certain that it should work.There,is the type of place,to me where you should take a look at the polarimetric system and compare it with the system in place.You have a very large ship,you have lots of room to put several systems on board and how much is it going to cost to put in six or seven passive reflectors.I would wager a lot less than the $250,000 or so that it cost to put in the transponders.

Comment:Mr.Ginsburg:

I just wanted to make a comment about GPS.Our own experience with the available satellites,a very crude experience using helicopters two years ago,we got something like 10 meters using differential mode.We have a receiver in the lab right now that with the Doppler aiding is repeatable to less than a meter.True we have been a little lazy and have not put it on to a ship yet but we are talking accuracies to centimeters.We are not talking about pie in the sky we are talking about something that is up there and it works.The real questions have to do with the shuttle disaster.The system works and it has been better than predicted.

Comment:Mr.Casey:

The electronic testbed that operated out of Halifax that you saw in the slides of Dr.Austin.I saw that last April and the course you saw on the slides are from actual GPS receivers.I saw that system operate with a GPS receiver and differential Loran-C.The differential Loran-C jumped around like crazy it couldn't follow a straight course looking at the chart but with straight GPS that was a straight course into Halifax harbor.

Comment:Mr.Lanziner:

I was just going to say that there was a recent article put out by Offshore Navigation in New Orleans,one of the

largest navigation companies particularly in the seismic field and the statement was made that Loran-C today is more accurate than differential or GPS or any combination thereof.Now I don't know what they based that on but it was a recent publication about two months ago.Now the dynamic version has not been proven.In the lab standing still or doing translocation certainly GPS is capable of centimeter accuracy if you wait long enough,similar to Transit.

Comment:Mr.Rudback:

I don't think anyone is trying to put down GPS it's going to come but people want navigation systems now and it's only available an hour a day right now but you have to integrate it with other things and when it finally comes along it will only help.

Comment:Mr.Ellwood:

I take the point that we have to do something between now and GPS.The concern for exportability is quite valid.It reflects the limited scale of Canadian market.When we look at this we tend to focus on the immediate,where's the market? I'd like to suggest that it's not Transport Canada's job.As for research is it feasible for us to assess the world market for these interim systems.There is no sense in developing a system for our market only we need something bigger.

Comment:Mr.MacArthur:

We in the DMA would certainly be interested in it.If we could demonstrate that it would save us money and enable us to operate more efficiently,we would definitely buy it.We have invested so much money already,but you have come to us at a time when we are not very prosperous.We are carrying wheat now for six dollars a ton which hardly pays for your fuel.So we are not really in a position to continue development.If you can demonstrate to us that this equipment when it is bought will save us money,someone mentioned something about pilotage,then we would certainly be very interested,very supportive.

It occurs to me that having put so much money into the industry,as Mr.Rudback suggested,perhaps it is now up to the industry to put in some of their own money to demonstrate to the world that not only has Canada got confidence in it but the Canadian manufacturers have the confidence to raise the money to invest the money and to put it on the market on their own.

Comment:Mr.Stiles:

I had hoped when everything had been said and done,and this is my final word,that sufficient funds will be made

available to at least complete the McMaster development,because in my humble opinion this has a lot of potential and will probably form the very heart of any future terrestrial navigation system.

Comment:Mr.Rudback:

We have already one demonstration that the system did save money that people are willing to invest in it.Coast Guard have demonstrated that in the Laurentian region that when the system is cost effective they will be interested.I know it's always difficult to raise money and carry on with the development either by the private sector or the government.Perhaps one way we can push things along is by going after targets of opportunity like Port Au Basques and proceed with implementation there and develop towards other implementations.

Comment:Mr.Williams:

I know for a fact that the traditional transponder systems don't work.That,they are not as reliable as we would like them to be.So we would like to try the polarimetric reflectors in Port Au Basques to see if they can give us better shore station reliability.

From my own past experience I might suggest that we should consider the English Channel as a possible market.That piece of waterway is extremely busy and they are already having problems with radar interference.The McMaster work may have some value there.

Comment:Mr.Kendrick:

One possible incentive I can see for DMA members to implement precise navigation systems on their ships brings us back to the point that Capt.McDowall made right at the start of this day.He would see the first and best use of this as an aid to Seaway season extension,when navigation lights come out.Again,as he mentioned,during the last two years it has been necessary to extend the Seaway season,to get the cargo moving,because of accidents in the system.Now that is costing somebody money.

Coast Guard budget,Coast Guard plans,are based on a specific season length.So are the budgets of the Seaway authority.If you were to allow ships fitted with a precise navigation system to operate beyond the normal length of the season,and others not to,then that might give a competitive advantage to the Canadian shipping industry and,if the cost of the system were,say, $70,000 that equates quite well with the profit that Capt.McDowall can make out of one extra trip.Could that be an area where the government could give active encouragement to DMA members to put a system on their ships?

Comment:Mr.Rudback:

I think one would have to see what that would translate into in dollars and cents.

Comment:Mr.Lanziner:

I think it's fairly easy to demonstrate that there are cost savings when you look at accidents.The area that we are concentrating in is areas where this technology is most beneficial,where the most critical situations are.A case Mr.Ginsburg mentioned,where the people in the Laurentian region of Coast Guard have been able to work 24 hours a day for the first time to clear ice and thereby keep the St.Lawrence free so that shipping could continue. The cost effectiveness of the system proved itself very easily.Now this was one case.If you extend that and go to all the problems with grounding it's easy to demonstrate costs.

It is not so easy to sell it that way.We are talking to Chevron shipping of Pascagoula Mississippi right now where they are doing lightering with tankers 750 feet long coming in through 15 mile long channels and they turn in an area that is 900 feet wide and they have four vessels going in and out all the time.In this type of application it can easily be shown that the cost of one accident will cost more than a whole bunch of these systems.But,you can't sell them that way.

Conmment:Mr.MacArthur:

The DMA is interested in continuing demonstrations but as I said we are on hard times right now.We did our original work because we were interested in extending the Seaway season but as Capt.McDowall has pointed out that is no longer the case due to a drop in business.If it can be demonstrated that it will save us money in other directions say in reduced underwriting then we are still strongly supportive.

Comment:Mr.Rudback:

The Deputy Minister keeps saying that safety is our prime concern.

Thank you,and I think that, that is an appropriate place to close this meeting.